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JOURNAL OF THE
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Volume 5 AUGUST, 1938 Number 10

Airfoil Theory for Non-Uniform Motion

TH. VON KÁRMÁN and W. R. SEARS, *California Institute of Technology*

(Received April 25, 1938)

ABSTRACT

The basic conceptions of the circulation theory of airfoils are reviewed briefly, and the mechanism by which a "wake" of vorticity is produced by an airfoil in non-uniform motion is pointed out. It is shown how the lift and moment acting upon an airfoil in the two-dimensional case may be calculated directly from simple physical considerations of momentum and moment of momentum. After a calculation of the induction effects of a wake vortex, formulae for the lift and moment are obtained which are applicable to all cases of motion of a two-dimensional thin airfoil in which the wake produced is approximately flat; *i.e.*, in which the movement of the airfoil normal to its mean path is small.

The general results are applied first to the case of an oscillating airfoil and then to the problem of a plane airfoil entering a "sharp-edged" gust. In the latter case the rate of increase of the lift after the entrance of the airfoil into the gust boundary is determined, and it is shown that during the entire process the lift acts at the quarter-chord point of the airfoil.

The intention of the authors has been to make the airfoil theory of non-uniform motion more accessible to engineers by showing the physical significance of the various steps of the mathematical deductions, and to present the results of the theory in a form suitable for immediate application to certain flutter and gust problems.

I. INTRODUCTION

THE theory of non-stationary motion around airfoils has important applications, perhaps the most significant problems involved being flutter and the forces experienced by airplanes flying through gusts. The theory has been developed by a number of authors, in particular Birnbaum, Wagner, Küssner, Glauert, and Theodorsen. However, the equations obtained by most of these authors are rather complicated, and in addition, the methods applied to the calculation of the forces are not especially transparent in the light of physical evidence. One of the English authors who recently dealt with the problem in a rather general manner declared that "the general formulae we have now obtained are rather too complex to convey directly any idea of their physical significance."[1] The idea of this paper is to eliminate unnecessary mathematical complications and to try to use only the basic conceptions of the vortex theory familiar to the modern aeronautical engineer.

It is advisable to review the fundamental conceptions of the circulation theory of airfoils for the case of two-dimensional motion, *i.e.*, of infinite aspect ratio. The airfoil put into motion creates a circulation around itself due to the presence of the sharp trailing edge; however, according to the theorem of conservation of moment of momentum, a counter-circulation develops in the fluid, called the "starting vortex." The airfoil and the starting vortex constitute a vortex-pair with an increasing distance between the two vortex lines, because the starting vortex remains at the place where it was created (neglecting its slow displacement perpendicular to the flight direction). Hence the momentum of the vortex pair, being proportional to the product of the circulation and the distance between the two vortices, increases continuously. The rate of this increase of the momentum is equal to the lift.

The first refinement of this simplified picture is the representation of the airfoil by a vortex sheet, *i.e.*, by a system of vortex lines with a continuous distribution of vorticity. Combined with the assumption that the starting vortex is so far behind the airfoil that it does not influence the flow at the airfoil, this leads to the so-

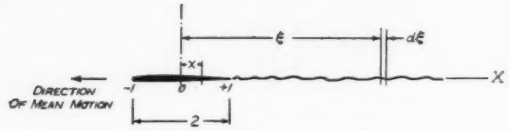

FIG. 1. Diagram showing notation employed.

called "stationary" theory of thin airfoils. However, if the total circulation around the airfoil is variable, because of non-uniformity of the motion, the airfoil leaves a wake composed of continuously distributed vortex lines behind itself, and the influence of this wake must be taken into account. The intensity of the vortex lines which constitute the wake is determined in this case by two conditions: (a) that the total circulation of the whole system is invariably equal to zero, and (b) that the wake vortices move with the fluid, *e.g.*, if the undisturbed fluid is at rest they keep their positions in space while the airfoil proceeds.

The method presented in this paper is based on the idea that the momentum per unit span of the system can be expressed by the sum of the momentum of the vortex pairs which constitute the system, where the momentum of each particular vortex pair is given by the product of the circulation and the distance between the individual vortices. It is assumed that all vortices are located along the X-axis; the circulation of a particular vortex is denoted by Γ_i, its X-coordinate by x_i, and the density of the fluid by ρ. Then the total momentum perpendicular to the X-axis is equal to $\rho\Sigma\Gamma_i x_i$, while the condition $\Sigma\Gamma_i = 0$ expresses the fact that the total circulation vanishes. The rate of change of the total momentum at any instant determines the magnitude of the lift. In a similar way the total moment of momentum of the fluid with respect to a suitably chosen point may be expressed. If the strengths of the two vortices of a particular vortex pair are denoted by $\pm\Gamma$, and the X-coordinates of the two vortices by x_1 and x_2, then the magnitude of the momentum is $\rho\Gamma(x_2 - x_1)$ and the line of action of the momentum, due to symmetry, is given by $x = (x_1 + x_2)/2$. Consequently the moment of momentum with respect to the origin of the coordinate system is equal to $\rho\Gamma(x_2^2 - x_1^2)/2$, and it is seen that the total moment of momentum of the system is given by the sum $(1/2)\rho\Sigma\Gamma_i x_i^2$. Hence the two equations

$$L = -\rho(d/dt)\Sigma\Gamma_i x_i \tag{1}$$

and

$$M = -(\rho/2)(d/dt)\Sigma\Gamma_i x_i^2 \tag{2}$$

determine the lift and the moment acting on the airfoil per unit span.

In the following sections this simple physical idea is carried out for the two-dimensional case of a thin airfoil with a wake composed of a plane vortex sheet. The general results are first applied to determine the forces and moments acting on an oscillating airfoil. This

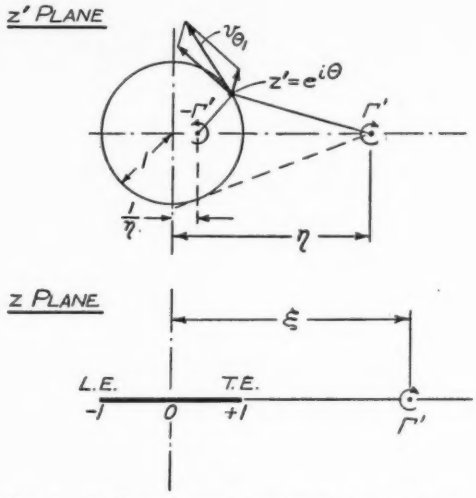

FIG. 2. Conformal representation of the airfoil and a wake vortex.

section (Section IV) is essentially a shortcut deduction of Glauert's, Küssner's, and Theodorsen's results. The next application refers to the penetration of an airfoil into a so-called "sharp-edged" gust. A simple proof of Küssner's theorem, previously not proved, concerning the line of action of the lift produced by the gust, is given. Then, in addition to the correction of some erroneous results of Küssner, a general method is developed for computing the lift produced by a gust of arbitrary shape.

Before the deduction of the general formulae for lift and moment, it appears desirable to recapitulate some simple calculations concerning the effect of a single vortex on a thin airfoil.

II. Calculation of the Effects of the Vortices in the Wake

The effects of the vortices in the wake are here calculated for the simple case shown in Fig. 1, under the following assumptions:

(a) that the flow about the airfoil is two-dimensional;

(b) that the vertical movement of any part of the airfoil is small, so that the airfoil and every point of the trail of vortices which it leaves behind may be considered to lie upon the X-axis;

(c) that the theory of thin airfoils can be applied to the calculation of the forces; in particular that the total circulation about the airfoil at any instant is such as to produce tangential flow at the trailing edge.

The effect of an element of vorticity, Γ', at a point ξ in the wake may be evaluated by the method of conformal transformation as pictured in Fig. 2. The transformation relating the two planes is

$$2z = z' + 1/z' \tag{3}$$

In the z'-plane the vortex $-\Gamma'$ is placed at $1/\eta$ to make the unit circle a streamline, by the usual method of "images." This means that the resultant velocity is tangential at all points on the circle. Its magnitude is

$$v_{\theta_1} = \frac{\Gamma'}{2\pi}\left|\frac{1}{z'-\eta} - \frac{1}{z'-1/\eta}\right|_{z'=e^{i\vartheta}} \tag{4}$$

By simple algebra, using the relations, from Eq. (3), $\eta + 1/\eta = 2\xi$ and $\eta - 1/\eta = 2\sqrt{\xi^2-1}$, this becomes

$$v_{\theta_1} = \frac{\Gamma'}{2\pi}\frac{\sqrt{\xi^2-1}}{\xi - \cos\theta} \tag{5}$$

In particular, the velocity at the trailing edge, where $\cos\theta = 1$, is equal to $(\Gamma'/2\pi)\sqrt{\xi+1}/\sqrt{\xi-1}$. In accordance with assumption (c) above, a circulation about the airfoil arises which is just great enough to cancel this velocity. Hence a second, uniform velocity $v_{\theta_2} = -(\Gamma'/2\pi)\sqrt{\xi+1}/\sqrt{\xi-1}$ is added to v_{θ_1}. Then the total tangential velocity becomes

$$v_\theta = \frac{\Gamma'}{2\pi}\left\{\frac{\sqrt{\xi^2-1}}{\xi-\cos\theta} - \sqrt{\frac{\xi+1}{\xi-1}}\right\} = -\frac{\Gamma'}{2\pi}\frac{1-\cos\theta}{\xi-\cos\theta}\sqrt{\frac{\xi+1}{\xi-1}} \tag{6}$$

The relation between the velocity v_θ and the vorticity distribution over the airfoil, $\gamma(x)$, is given by the formula $\gamma(x) = -2v_\theta/\sin\theta$ (cf. von Kármán and Burgers,[2] page 46, noting that their transformation differs by a factor of 2 from the one given in Eq. (3)). Thus, from Eq. (6), it follows that

$$\gamma(x) = \frac{1}{\pi}\frac{\Gamma'}{\xi-x}\sqrt{\frac{1-x}{1+x}}\sqrt{\frac{\xi+1}{\xi-1}} \tag{7}$$

This vorticity distribution on the airfoil is plotted in Fig. 3 for several values of ξ. It is seen that a wake vortex located one half-chord length or more behind the trailing edge induces a vorticity distribution which is similar to the well-known one produced by a small angle of attack, while a vortex placed very close to the airfoil induces a much stronger vorticity over the chord, with a definite peak near the trailing edge in addition to that at the leading edge.

The total circulation is obtained by integration of Eq. (7), and is

$$\Gamma = \int_{-1}^{1}\gamma(x)dx = \Gamma'\{\sqrt{(\xi+1)/(\xi-1)} - 1\} \tag{8}$$

III. General Expressions for the Lift and Moment

In the following calculations the chord of the airfoil is again taken as 2, so that all distances are measured relative to the half-chord length. All forces are calculated for a unit length in the spanwise direction. The

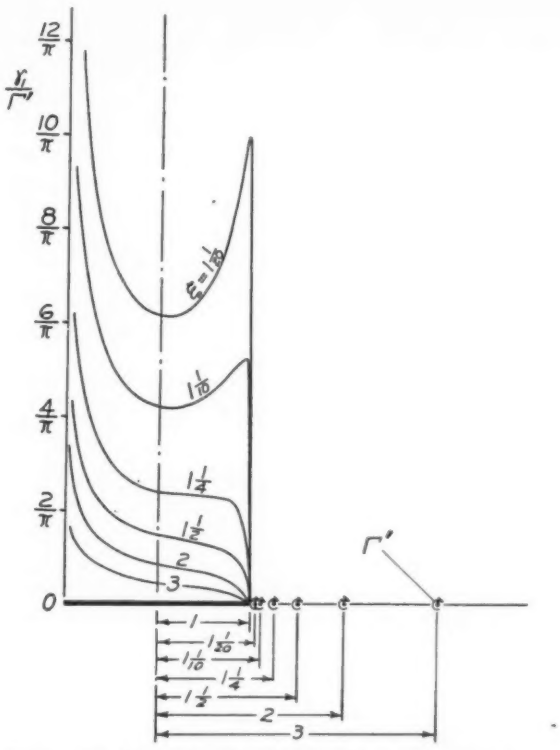

FIG. 3. Vorticity distributions induced by a wake vortex at various distances from the midpoint of the airfoil.

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(a) the vorticity, $\gamma_0(x)$, which would be produced, according to the thin airfoil theory, by the motion of the airfoil or the given velocity distribution (gust) in the air, if the wake had no effect. $\gamma_0(x)$ is called the "quasi-steady" vorticity distribution;

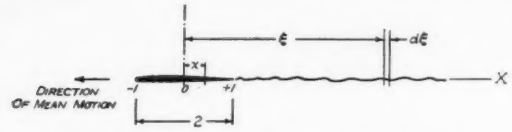
(b) the vorticity, $\gamma_1(x)$, which is induced by the wake, as calculated in the preceding section.

The circulation resulting from (a) is denoted by Γ_0, and that from (b) by Γ_1; the total circulation about the airfoil is then $\Gamma = \Gamma_0 + \Gamma_1$. According to the basic conceptions explained in Section I, the total circulation of the whole system must be zero, hence

$$\Gamma + \int_1^\infty \gamma(\xi)d\xi = 0 \tag{9}$$

The contribution Γ_1 of the wake can be calculated using Eq. (8). Putting $\Gamma' = \gamma(\xi)d\xi$ and integrating over the whole length of the wake,

$$\Gamma_1 = \int_1^\infty (\sqrt{(\xi+1)/(\xi-1)} - 1)\gamma(\xi)d\xi \tag{10}$$



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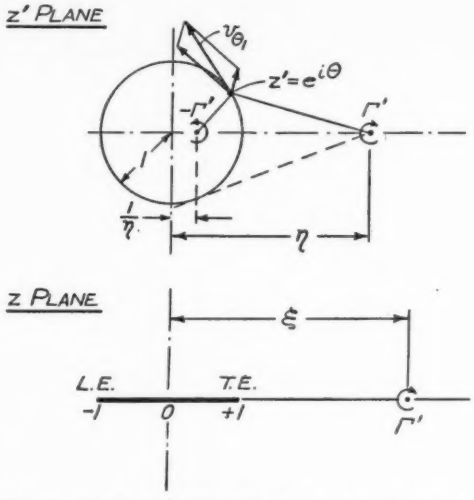

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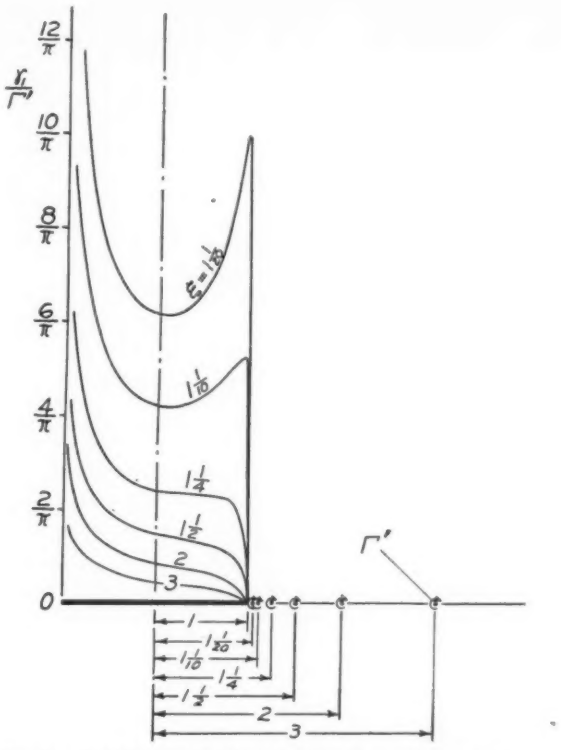

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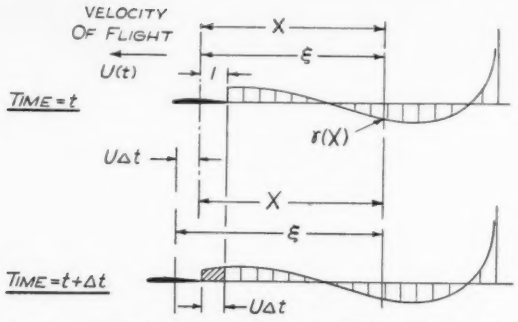

FIG. 4. Auxiliary diagram used in the calculation of the time derivatives of integrals over the wake.

Hence the circulation about the airfoil at any instant is given by

$$\Gamma = \Gamma_0 + \int_1^\infty (\sqrt{(\xi+1)/(\xi-1)} - 1)\gamma(\xi)d\xi \quad (10a)$$

From Eq. (9) it is seen that the following relation holds between the quasi-steady circulation and the vorticity in the wake:

$$\Gamma_0 + \int_1^\infty \gamma(\xi)\sqrt{(\xi+1)/(\xi-1)}\,d\xi = 0 \quad (11)$$

This relation will be employed later on in the paper.

The total circulation of the system being equal to zero, according to Eq. (9), the system can be considered as composed of vortex pairs and apply Eqs. (1) and (2) for the computation of lift and moment.

As was mentioned in Section I, the total momentum per unit length of a two-dimensional system of vortex pairs lying along the X-axis is equal to $\rho\Sigma\Gamma_i x_i$. Hence the total momentum of the system of continuously distributed vortices consisting of the airfoil and its wake is

$$I = \rho\int_{-1}^{1}\gamma(x)x\,dx + \rho\int_1^\infty \gamma(\xi)\xi\,d\xi \quad (12)$$

Substituting $\gamma(x) = \gamma_0(x) + \gamma_1(x)$ and using Eq. (7) for $\gamma_1(x)$, replacing Γ' by $\gamma(\xi)d\xi$,

$$\int_{-1}^{1}\gamma(x)x\,dx = \int_{-1}^{1}\gamma_0(x)x\,dx + \frac{1}{\pi}\int_{-1}^{1}\sqrt{\frac{1-x}{1+x}}\,x\,dx\int_1^\infty \frac{\gamma(\xi)}{\xi-x}\sqrt{\frac{\xi+1}{\xi-1}}\,d\xi \quad (13)$$

When the integration with respect to x in the last term is carried out, the double integral is reduced to $\pi\int_1^\infty \gamma(\xi)(\sqrt{\xi^2-1} - \xi)d\xi$ and therefore

$$I = \rho\int_{-1}^{1}\gamma_1(x)x\,dx + \rho\int_1^\infty \gamma(\xi)\sqrt{\xi^2-1}\,d\xi \quad (14)$$

Now it is desired to differentiate this expression to obtain the lift, but since $\partial\gamma(\xi)/\partial\xi$ may be discontinuous at certain points in the wake (*e.g.*, the case considered in Section VI of this paper), the use of an integration by parts (as employed in reference 2, page 301) is not allowable in the evaluation of the second term. Since a similar problem is encountered later in calculating the moment, it is desirable to consider a general integral of the form

$$A = \int_1^\infty \gamma(\xi)f(\xi)d\xi$$

The wake vorticity, γ, according to the assumptions already made, is stationary relative to the fluid. Hence if X is the distance of an arbitrary wake vortex from a fixed origin, say from the location of the center of the airfoil at the instant $t = t$, then γ is a function of X only. The integral considered can therefore be written

$$A = \int_1^\infty \gamma(X)f(\xi)d\xi$$

If A is the value of this integral at the time t and $A + \Delta A$ the value at the time $t + \Delta t$, and if account is taken of the fact that the airfoil has moved through a distance $U\Delta t$ during this interval, where U is the velocity of flight, so that $\xi = X + U\Delta t$ (cf. Fig. 4), it is seen that

$$A + \Delta A = \int_{1-U\Delta t}^\infty \gamma(X)f(X + U\Delta t)dX$$

Neglecting terms of second order and higher,

$$\Delta A = \int_{1-U\Delta t}^{1}\gamma(X)f(X)dX + U\Delta t\int_1^\infty \gamma(X)f'(X)dX$$

Now if $\gamma(X)$ is finite in the interval and if $f(1) = 0$, then in the limit $\Delta t \longrightarrow 0$ the first term vanishes, and, replacing X by ξ in the second term,

$$dA/dt = U\int_1^\infty \gamma(\xi)f'(\xi)d\xi \quad (15)$$

Applying this result in the differentiation of the second term of Eq. (14), the lift becomes

$$L = -dI/dt = -\rho\frac{d}{dt}\int_{-1}^{1}\gamma_0(x)x\,dx - \rho U\int_1^\infty \gamma(\xi)\xi\,d\xi/\sqrt{\xi^2-1} \quad (16)$$

Using Eq. (11) the lift may also be written in the form

$$L = -\rho\frac{d}{dt}\int_{-1}^{1}\gamma_0(x)x\,dx + \rho U\Gamma_0 + \rho U\int_1^\infty \gamma(\xi)\,d\xi/\sqrt{\xi^2-1} \quad (16a)$$

Thus the lift consists of three parts:

(a) $L_1 = -\rho(d/dt)\int_{-1}^{1}\gamma_0(x)x\,dx$, which will be called the contribution of the apparent mass;

(b) $L_0 = \rho U\Gamma_0$, the quasi-steady lift;

(c) $L_2 = \rho U \int_1^\infty \gamma(\xi)d\xi/\sqrt{\xi^2-1}$. This is the only contribution which depends explicitly on $\gamma(\xi)$, the vorticity distribution in the wake.

In a similar manner, the total moment of momentum per unit span of the system, referred to a fixed axis, may be calculated. It is $M_m = (1/2)\rho\Sigma\Gamma_i x_i^2$. If the center of the airfoil is imagined to be at a distance s from the fixed axis,

$$M_m = \frac{1}{2}\rho\int_{-1}^{1}\gamma(x)(x+s)^2dx + \frac{1}{2}\rho\int_1^\infty \gamma(\xi)(\xi+s)^2d\xi \quad (17)$$

where x and ξ are again measured from the center of the airfoil. The moment M acting on the airfoil, referred to its midpoint, is then given by the value of dM_m/dt for $s = 0$. Carrying out the differentiation and taking into account that $ds/dt = -U$, where U is the velocity of flight of the airfoil, this becomes

$$M = -\frac{1}{2}\rho\frac{d}{dt}\left\{\int_{-1}^{1}\gamma(x)x^2dx + \int_1^\infty \gamma(\xi)\xi^2d\xi\right\} + UI \quad (18)$$

where I is the total momentum as calculated in Eq. (14). A diving moment is here considered positive.

Now substituting again $\gamma(x) = \gamma_0(x) + \gamma_1(x)$, and using Eq. (7), an analysis similar to that leading to Eq. (14) gives

$$M = -\frac{1}{2}\rho\frac{d}{dt}\left\{\int_{-1}^{1}\gamma_1(x)x^2dx + \frac{1}{2}\int_1^\infty \gamma(\xi)\sqrt{\frac{\xi+1}{\xi-1}}\,d\xi + \int_1^\infty \gamma(\xi)\xi\sqrt{\xi^2-1}\,d\xi\right\} + UI \quad (19)$$

If the second integral in the bracket is replaced according to Eq. (11) and the differentiation of the third integral is carried out by the method of Eq. (15), then, by substitution for I from Eq. (14), the moment becomes

$$M = -\frac{1}{2}\rho\frac{d}{dt}\int_{-1}^{1}\gamma_0(x)[x^2-(1/2)]dx + \rho U\int_{-1}^{1}\gamma_0(x)xdx - \frac{1}{2}\rho U\int_1^\infty \gamma(\xi)d\xi/\sqrt{\xi^2-1} \quad (20)$$

Therefore, the moment also consists of three parts:

(a) $M_1 = -(1/2)\rho(d/dt)\int_{-1}^{1}\gamma_0(x)[x^2-(1/2)]dx$, analogous to L_1;

(b) M_0, the quasi-steady moment;

(c) M_2, the last term, depending explicitly upon the vorticity in the wake. Since $M_2 = -L_2/2$, the lift L_2 always acts through the quarter-chord point of the airfoil ($x = -1/2$).

According to Eqs. (16a) and (20), both lift and moment consist of three parts, itemized under (a), (b), and (c) above. The physical significance of these contributions will now be explained briefly.

Considering first the lift, let it be assumed that the airfoil carries out its motion without producing circulation. Then the quasi-steady lift is zero, and, because obviously no wake is produced, the part called L_2 also vanishes. It is known from general principles that in such a case the only forces acting on a body moving in an ideal fluid are those corresponding to the apparent mass of the body. These can be obtained by integrating over the surface of the airfoil the so-called "impulsive pressures," $\rho(\partial\varphi/\partial t)$, where φ is the velocity potential of the circulationless flow. Hence, if C indicates a path of integration starting at some point A on the airfoil and going completely around the airfoil profile back to A, the lift is

$$\rho\int_C \frac{\partial\varphi}{\partial t}ds = \rho\frac{\partial}{\partial t}\int_C \varphi ds = \rho\frac{\partial}{\partial t}\left\{\varphi s\Big|_A^A - \int_C \frac{\partial\varphi}{\partial s}sds\right\}$$

where s represents the distance along the surface. Now the first term obtained in the integration by parts is obviously equal to zero, since there is no circulation and therefore φ is single-valued. Also, for a thin airfoil, $\partial\varphi/\partial s$, which is the velocity along the surface of the airfoil, is equal to $\gamma_0(s)/2$ because the surface velocities on opposite sides of the airfoil at any point are equal and opposite and $\gamma_0(s)$, the vorticity at s, is their difference. Therefore, the lift for this case is simply

$$-\rho(d/dt)\int_C \gamma_0(s)sds/2 = -\rho(d/dt)\int_{-1}^{1}\gamma_0(x)xdx$$

which is exactly the term called L_1 above.

Therefore, the term L_1 gives correctly the lift due to the apparent mass in the case of the airfoil without circulation. Now the addition of circulation increases the function $\gamma_0(x)$ by a term equal to $(\Gamma_0/\pi)/\sqrt{1-x^2}$, which is the vorticity distribution of a pure circulation about a plane airfoil. It is seen by considerations of symmetry that this term does not contribute to the integral L_1. As far as the corresponding part of the moment is concerned, in the case of flow without circulation the integral $-(1/2)\rho(d/dt)\int_{-1}^{1}\gamma_0(x)x^2dx$ gives the moment due to the apparent mass distribution, as can easily be verified by integrating the moments of the impulsive pressures in a manner similar to that used above for the lift. The rest of the integral called M_1 above vanishes because $\int_{-1}^{1}\gamma_0(x)dx = 0$. Again the addition of the circulation term to $\gamma_0(x)$ does not change the value of the whole integral, for this term is $(\Gamma_0/\pi)/\sqrt{1-x^2}$, and

$$\frac{\Gamma_0}{\pi}\int_{-1}^{1}\frac{x^2-(1/2)}{\sqrt{1-x^2}}\,dx = 0$$

Hence it is found that the contributions under (a), above, L_1 and M_1, are equal to the force and moment which the airfoil would encounter in a flow without circulation, due to the reaction of the accelerated fluid masses. These contributions in both cases are called

the "apparent mass contributions." It should be noted that the determination of $\gamma_0(x)$ involves only the solution of steady-motion problems and can be done in any given case by the use of known formulae of the stationary airfoil theory.

The contributions under (b), above, the lift L_0 and moment M_0, are easily interpreted. They represent the force and moment which would be produced if the instantaneous velocity and angle of attack of the airfoil were permanently maintained. The calculation of L_0 and M_0 also requires only the solution of stationary problems by the usual methods.

The third contributions, L_2 and M_2, represent the influence of the wake. Their interpretation is simplified by considering a case in which quasi-steady lift and moment (*i.e.*, the angle of attack or speed) undergo a sudden change at the instant $t = 0$ and are kept constant for $t > 0$. In this case $L_1 = M_1 = 0$ for $t > 0$, and the lift and moment are given by $L_0 + L_2$ and $M_0 + M_2$. For $t = \infty$ the final values of lift and moment will be L_0 and M_0 because the conditions of the "stationary" case are approached. It is seen that L_2 and M_2 give the difference between the instantaneous and final values of lift and moment. Hence $-L_2$ and $-M_2$ can be called the "deficiencies" caused by the non-uniformity of the motion of the airfoil or of the wind velocity encountered by it.

Before proceeding to the next section, it should be pointed out that the general formulae, Eqs. (16a) and (20), developed in this section, can be applied to the case of any thin airfoil with arbitrary shape, performing an arbitrary (accelerated, oscillatory, or uniform) motion, provided only that its deviation from a straight path is small, so that the assumption of a wake distributed along a straight line is justified.

It may be pointed out that the momentum of the fluid can again be expressed in terms of the characteristics of the vortex system in the case of a wing of finite span. The authors hope to extend the methods used here to that case and to obtain analogous results.

IV. Application to the Case of Steady-State Oscillations

The theory of steady-state oscillations of an airfoil has a bearing on many practically important problems. Actually it was first developed in anticipation of flying machines with flapping wings. Later it was found to be closely connected with the theory of wing flutter. In the earliest flutter theories, it was assumed that the forces acting on the oscillating airfoil could be approximated by those referred to in the preceding section as quasi-steady forces plus some damping forces assumed more or less arbitrarily on the basis of a few wind-tunnel experiments. However, the lag between the actual forces and the quasi-steady forces and the influence of the apparent mass could not be taken into account in this way. The theory of the oscillating airfoil now opens the way to a more systematic estimate of the forces. To be sure, the assumption of infinite aspect ratio restricts the accuracy of purely theoretical predictions for the flutter of wings of finite spans, but in any case the results obtained by the theory aid in scientific analysis of experimental data obtained in the laboratory and with actual airplanes in flight. The experimental work done by Küssner and others has shown that the so-called "reduced frequency" (*i.e.*, the product of half-chord and vibration frequency divided by the flying speed) is the most adequate parameter for the discussion of flutter data. The following analysis leads to simple formulae and diagrams showing how the magnitude and the phase of the actual lift and moment depend on the reduced frequency.

If the motion of the airfoil is periodic, the resulting quasi-steady circulation is also periodic and, using the complex variable notation, may be written

$$\Gamma_0 = G_0 e^{i\nu t} \tag{21}$$

where G_0 is a constant.

If the motion has been occurring so long that transient phenomena have disappeared, it may be assumed that the vortex strength in the wake can be expressed as

$$\gamma(\xi) = g e^{i\nu[t-(\xi/U)]} \tag{22}$$

where g is also a constant and U is the constant mean horizontal velocity.

Then the total circulation about the airfoil is given (from Eq. (10a)) by

$$\Gamma = e^{i\nu t}\left[G_0 + g\int_1^\infty \left(\sqrt{\frac{\xi+1}{\xi-1}} - 1\right) e^{-i\nu\xi/U} d\xi\right] \tag{23}$$

Hence Γ is also a periodic function of the time, and, because the wake vorticity is produced by the changes of circulation of the airfoil, the increment of circulation, $(d\Gamma/dt)dt$, must be equal and opposite to the circulation in the wake between $\xi = 1$ and $\xi = 1 + Udt$. Consequently $(d\Gamma/dt)dt = -\gamma(1)Udt$. By differentiation of Eq. (23) and substitution of $d\Gamma/dt = -\gamma(1)U$, the following relation between G_0 and g is obtained:

$$-\frac{G_0}{g} = \int_1^\infty \left(\frac{1+\xi}{\sqrt{\xi^2-1}} - 1\right) e^{-i\nu\xi/U} d\xi + \frac{U}{i\nu} e^{-i\nu/U} \tag{24}$$

The right side of Eq. (24) can be expressed as the sum of two modified Bessel functions of the second kind of the argument $iz = i\nu/U$, namely

$$K_0(iz) = \int_1^\infty e^{-iz\xi} d\xi/\sqrt{\xi^2-1} \text{ and } K_1(iz) = -K_0'(iz)$$

(See reference 3; Eq. (29), page 50, and Eq. (19), page 22.) Using K_0 and K_1 as abbreviations for $K_0(i\nu/U)$ and $K_1(i\nu/U)$, the result obtained* is

* The integral $\int_1^\infty e^{-i\nu\xi/U} d\xi/\sqrt{\xi^2-1}$ is easily identified as $K_0(i\nu/U)$. That the rest of the right side of Eq. (24) is equal to

$$-G_0/g = K_0 + K_1 \tag{25}$$

In any given case of periodic motion $g_0(x)$ and G_0 can be easily calculated, and they determine directly the first two terms of the expressions for lift and moment, Eqs. (16a) and (20). After substitution of $\gamma(\xi)$ from Eq. (22) and g from Eq. (25), the third term of Eq. (16a) becomes

$$L_2 = -\rho U G_0 e^{i\nu t}(K_0 + K_1)^{-1} \int_1^\infty e^{-i\nu\xi/U} d\xi/\sqrt{\xi^2 - 1}$$

or

$$L_2 = -\rho U G_0 e^{i\nu t} K_0/(K_0 + K_1) \tag{26}$$

The corresponding moment is $M_2 = -L_2/2$.

These results will now be applied to the case of an airfoil performing (1) translatory oscillations normal to the flight direction, and (2) rotational oscillations around its midpoint.

Case 1. Translatory Oscillation

For this case the vertical velocity of every point of the airfoil can be written as

$$w = A_0 U e^{i\nu t} \tag{27}$$

where A_0 is a constant and w is taken as positive downward. The quasi-steady portion of the vorticity depends only on the instantaneous relative velocity of the air and the airfoil, and therefore the quasi-steady quantities can be calculated by the formulae of reference 2, Chapter 2, by replacing v_y by $-w$. For the present case (from reference 2, page 38, putting $c = 2$)

$$G_0 = \Gamma_0/e^{i\nu t} = 2\pi U A_0$$

$$g_0(x) = \gamma_0(x)/e^{i\nu t} = 2UA_0(1 - \cos\theta)/\sin\theta \tag{28}$$

where again $x = \cos\theta$

The three parts of the lift, as in Eq. (16a), are therefore

$$L_0 = 2\pi\rho U^2 A_0 e^{i\nu t}$$

$$L_1 = \pi\rho i\nu U A_0 e^{i\nu t}$$

and, from Eq. (26),

$$L_2 = -2\pi\rho U^2 A_0 e^{i\nu t} K_0/(K_0 + K_1)$$

The total lift is therefore

$$L = 2\pi\rho U^2 e^{i\nu t} A_0 \left\{ \frac{K_1(i\nu/U)}{K_0(i\nu/U) + K_1(i\nu/U)} + \frac{i\nu}{2U} \right\} \tag{29}$$

$-K_0'(iz)$ can be shown in the following way, which avoids convergency difficulties: Write

$$K_0(iz) = \int_1^\infty e^{-iz\xi} d\xi/\sqrt{\xi^2 - 1} - \int_1^\infty e^{-iz\xi} d\xi/\xi + \int_z^\infty e^{-il} dl/l$$

which is obviously correct because the difference between the second and third integrals vanishes identically. By differentiation with respect to iz and substitution of $z = \nu/U$, the identification is completed.

It is seen that L_1 is equal to the product of the acceleration, $A_0 U i\nu e^{i\nu t}$, and the apparent mass of a flat plate of length = 2, which is equal to $\pi\rho$.

The apparent-mass contribution to the moment, M_1, vanishes, since the motion is purely translatory and the apparent-mass lift acts through the center of the airfoil. This can be verified by substituting $g_0(x)$ from Eq. (28) into the first term of Eq. (20) and integrating. The quasi-steady lift in this case acts at the quarter-chord point ($x = -1/2$), as does L_2. The total moment is therefore

$$M = -(L_0 + L_2)/2$$

$$= -\pi\rho U^2 e^{i\nu t} A_0 \frac{K_1(i\nu/U)}{K_0(i\nu/U) + K_1(i\nu/U)} \tag{30}$$

Case 2. Rotational Oscillation

In this case the vertical velocities of the various points of the airfoil are given by

$$w = 2U e^{i\nu t} A_1 \cos\theta \tag{31}$$

In this case the formulae of reference 2 lead to the following expressions for the quasi-steady quantities:

$$G_0 = 2\pi U A_1$$

$$g_0 = 4UA_1 \sin\theta \tag{32}$$

By substitution into Eqs. (16a) and (26), then,

$$L_0 = 2\pi\rho U^2 e^{i\nu t} A_1$$

$$L_1 = 0$$

$$L_2 = -2\pi\rho U^2 e^{i\nu t} A_1 K_0/(K_0 + K_1)$$

so that the total lift in this case becomes*

$$L = 2\pi\rho U^2 e^{i\nu t} A_1 \frac{K_1(i\nu/U)}{K_0(i\nu/U) + K_1(i\nu/U)} \tag{33}$$

Also, by substitution into Eq. (20),

$$M_1 = \pi\rho U A_1 e^{i\nu t} i\nu/4$$

$$M_0 = 0$$

and

$$M_2 = -L_2/2$$

Therefore, the total moment is*

$$M = \pi\rho U^2 e^{i\nu t} A_1 \left\{ \frac{K_0(i\nu/U)}{K_0(i\nu/U) + K_1(i\nu/U)} + \frac{i\nu}{4U} \right\} \tag{34}$$

* It should be noted that Eqs. (33) and (34) give only the portions of lift and moment which are due to the angular velocity of the airfoil. The effects of the periodic changes in angle of attack which actually accompany the rotation are to be obtained from the results of Case 1. Since the instantaneous angle of attack is equal to $2UA_1 e^{i\nu t}/i\nu$, these contributions are evaluated by taking A_0 of Case 1 equal to $2UA_1/i\nu$.

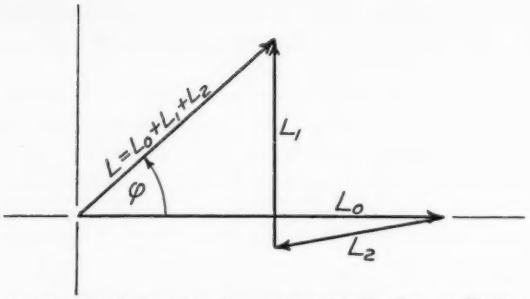

FIG. 5. Typical vector diagram for the lift of an oscillating airfoil.

In a similar manner, the lift and moment on the airfoil may be calculated for the cases of periodic deformations represented by higher values of n in the general expression for the vertical velocity of any point of the airfoil:

$$w(\theta) = Ue^{i\nu t}\left\{A_0 + 2\sum_{n=1}^{\infty} A_n \cos n\theta\right\} \qquad (35)$$

The results, including those of Cases 1 and 2 above, agree with those obtained by Küssner.[4]*

The physical significance of the complex forms of Eqs. (29), (30), (33), and (34) may be clarified by means of "vector diagrams" which show the phase relationships of the quantities involved as well as their magnitudes. Each of these results may be abbreviated as

$$f(t) = Fe^{i\nu t}\{f_1(\nu/U) + if_2(\nu/U)\} \qquad (36)$$

where $f(t)$ represents the lift or moment; F is a constant involving only the dynamic pressure, $\rho U^2/2$, and the amplitude of the oscillation; and f_1 and f_2 are real functions. The real part of this expression (which is the actual force or moment) may be written as

$$\begin{aligned} R[f(t)] &= F\{f_1 \cos \nu t - f_2 \sin \nu t\} \\ &= F\sqrt{f_1^2 + f_2^2}\cos(\nu t + \varphi) \end{aligned} \qquad (37)$$

where $\varphi = \tan^{-1}(f_2/f_1)$. Thus, in vector representation, the lift or moment vector has the magnitude $F\sqrt{f_1^2 + f_2^2}$ and leads the vector of the oscillating velocity, w, by a phase angle, φ. In Fig. 5 is given an example, taken from Case 1, above, which shows schematically how the total lift vector is composed of the vectors L_0, L_1, and L_2 for a certain value of ν/U. The quasi-steady part, L_0, being in phase with the velocity, appears as a horizontal vector, while the vector, L_2, tends to diminish the lift and cause it to lag behind the velocity. The apparent-mass lift, L_1, being proportional to the acceleration, is directed vertically, *i.e.*, leads the velocity by 90°. The total lift, L, is the sum of these three vectors, and has the phase angle φ.

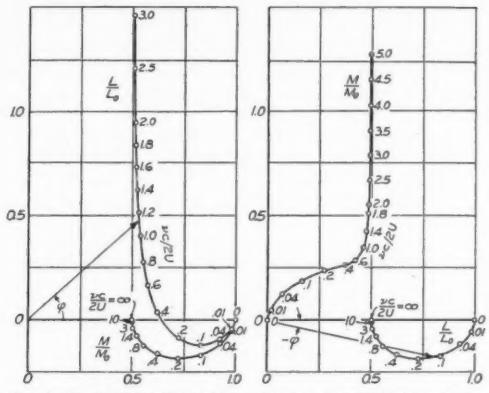

FIG. 6. Vector diagrams for the lift and moment of oscillating airfoils, as functions of the reduced frequency. L_0 and M_0 are the respective quasi-steady values. (In the right-hand diagram, M_0 should be replaced by $\pi\rho U^2 e^{i\nu t}A_1$, as defined in the text.)

In Fig. 6 are plotted "vector diagrams" which give the magnitudes of the lift and moment together with their phase angles for various values of the reduced frequency ν/U (or $c\nu/2U$ for an airfoil of chord = c).† In these diagrams the length of the vector drawn from the origin to the appropriate value of $c\nu/2U$ on the curve gives the maximum value of the total lift or moment (referred to that of the corresponding quasi-steady quantity, L_0 or M_0), and its angle with the horizontal axis gives the phase angle relative to w. It is seen that as the frequency of the translatory oscillation (Case 1) is increased from $c\nu/2U = 0$ (uniform motion) the maximum value or amplitude of the lift at first steadily decreases, and the lift vector lags slightly behind the vertical-velocity vector, w. These effects are produced by the wake contribution, L_2. With further increase of the frequency, however, the apparent-mass contribution, L_1, which is proportional to the acceleration, becomes very large, and the lift vector leads the velocity vector. In the limit $c\nu/2U \longrightarrow \infty$ the sum $(L_0 + L_2)$ is equal to half of L_0, but $L_1 \longrightarrow \infty$, and the lift vector leads w by 90°. Since the apparent-mass lift, L_1, acts through the midpoint of the airfoil in this case, the limiting value of the moment is also half of its steady-motion value. In the rotational case (Case 2) the total lift behaves exactly like the moment of Case 1 as the frequency is increased, while the apparent-mass moment contribution, M_1, increases proportionally to the frequency.

It is believed that the method of representation of lift and moment by vector diagrams will be useful in the discussion of flutter problems because both the elastic restoring forces and the inertia forces of the wing can be introduced in such diagrams. It is intended to extend the work in this direction.

* In comparing Küssner's results, it should be noted that

$$\pi H_n^{(2)}(z) = 2i^{(n+1)}K_n(iz)$$

Also Küssner's $(-i\omega)$ is the same as (ν/U) here, and, because of the difference in definition of θ, his P_n is $(-)^n A_n$ of the present paper.

† Küssner[4] (page 416) gives a table of Bessel functions involved in the calculation of Fig. 6.

The results presented in Fig. 6 are applicable to cases of bending-torsional wing flutter. The calculation of aileron or rudder flutter requires the expression of the non-steady forces acting on the aileron or rudder in a similar way. The aileron or rudder constitutes one portion of a wing or a fin, while the equations presented in this paper give only the lift and moment acting on the wing as a whole. However, by determining the vorticity distribution produced by the wake, similar equations can be deduced for the non-steady normal force on the aileron and for the non-steady hinge moment. Both Küssner and Theodorsen have published such calculations, but it is felt that extension of the methods presented in this paper to the aileron case might facilitate understanding of the physical principles involved and reduce the amount of mathematical work required.

V. General Method for Transient Phenomena

There are many cases in which knowledge of the forces produced by a transient phenomenon is of practical interest. Examples of such cases are the reaction of an airplane to certain control operations (aileron or rudder deflection, etc.), and the behavior of an airplane encountering gusts. In the second case, an estimate of the forces acting on the wing is of importance, as well as the reaction of the airplane as a whole, in view of strength requirements. It is believed that the general method developed in the following paragraphs will be useful in many such transient problems.*

In order to determine the response of the system to a "unit disturbance," it is first assumed that the velocity of flight, U, is constant, and that the quasi-steady circulation, Γ_0, changes suddenly from zero to unity at the time $t = 0$ and remains constant for $t > 0$. Then the wake extends from $\xi = 1$ to $\xi = 1 + Ut$, and, according to Eq. (11),

$$\Gamma_0 = 1 = -\int_1^{1+Ut} \gamma(\xi)\sqrt{(\xi+1)/(\xi-1)}\,d\xi \quad (38)$$

The vortex strength in the wake is a function of the distance s from the endpoint of the wake, $s = 1 + Ut - \xi$, hence it may be written as $\gamma(\xi) = \mu(1 + Ut - \xi)$. Eq. (38) represents an integral equation for μ in the form

$$-\int_1^{1+Ut} \mu(1 + Ut - \xi)\sqrt{(\xi+1)/(\xi-1)}\,d\xi = 1$$

or, introducing the variable s,

$$-\int_0^{Ut} \mu(s)\frac{\sqrt{2 + Ut - s}}{\sqrt{Ut - s}}ds = 1 \quad (39)$$

* The elementary cases, *e.g.*, the airfoil put suddenly into motion or suddenly given a certain angle of attack, have been treated by H. Wagner.[5] Küssner[4] has developed a more general method using the conception of the Fourier integral.

The function $\mu(s)$ has been determined by Wagner.[5]

For the following applications, the main problem is the calculation of L_2, the contribution of the wake. For the case being considered, L_2 is equal to (from Eq. (16a))

$$\rho U\int_1^{1+Ut} \gamma(\xi)d\xi/\sqrt{\xi^2-1} = \rho U\int_1^{1+Ut} \mu(1 + Ut - \xi)\,d\xi/\sqrt{\xi^2-1} \quad (40)$$

where the function $\mu(s)$ is again the solution of the integral equation (Eq. (39)). The function

$$\Phi(Ut) = -\int_1^{1+Ut} \mu(1 + Ut - \xi)d\xi/\sqrt{\xi^2-1} \quad (41)$$

will be called the lift-deficiency function. It represents the difference between the instantaneous and final values of the lift in the case of sudden unit increase of the quasi-steady circulation, and is a function of the distance Ut traveled by the airfoil since the change of circulation took place.

It is evident that the function Φ can be used to calculate the lift acting on an airfoil which is subjected to an arbitrary transient variation of the quasi-steady circulation Γ_0. Assuming that Γ_0 changes at the instant τ by the increment $\Delta\Gamma_0 = \Gamma_0'(\tau)\,\Delta\tau$, the deficiency in lift at $t = t$, *i.e.*, after the airfoil has traveled a distance $U(t - \tau)$ will be $\Gamma_0'(\tau)\Phi[U(t - \tau)]\,\Delta\tau$ and the total deficiency in lift will be given by

$$-L_2 = \rho U\int_0^t \Gamma_0'(\tau)\Phi[U(t-\tau)]d\tau \quad (42)$$

In this equation it is assumed that $\Gamma_0(0) = 0$. If, at the instant $t = 0$, Γ_0 is suddenly increased from 0 to $\Gamma_0(0)$, a term equal to $\Gamma_0(0)\,\Phi(Ut)$ is to be added to the right-hand side of Eq. (42).

The elementary case of a sudden unit increment in Γ_0 has been treated by Wagner, and the function $1 - \Phi$ is equal to his $A/2b\pi\rho v^2 \sin\beta$ (see page 31 of reference 5; also Fig. 9 and Table 2). Thus the lift and moment can be calculated by Eqs. (16a) and (20), for a given $\gamma_0(x,t)$ distribution, because L_0, L_1, M_0, M_1 are determined by γ_0 and its time derivative, L_2 is given by (42), and $M_2 = -L_2/2$.

The function $\Phi(Ut)$ is not given in analytical form because it requires the solution of the integral Eq. (38). However, it can be fairly closely approximated by the following relatively simple formulae which are chosen so as to facilitate subsequent calculations.

(a) for $0 \leqq \sigma \leqq 2$ the following power series can be used:

$$\Phi(\sigma) = (1/2) - (\sigma/8) + (\sigma^2/32) - 0.00554\,\sigma^3 \quad (43)$$

(b) for $0 \leqq \sigma \leqq 10$

$$\Phi(\sigma) = (e^{-\sigma/2}/4) + (1 + 0.185\,\sigma)e^{-0.185\sigma}/4 \quad (44)$$

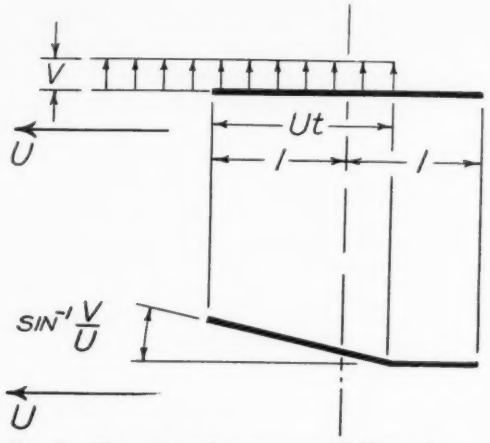

FIG. 7. The analogy between an airfoil entering a sharp-edged gust and a broken-line airfoil.

However, $1 - \Phi$ enters in the final result, and since $\Phi(\sigma)$ is very small for $\sigma > 10$, Eq. (44) can be applied for $0 \leqq \sigma \leqq \infty$ without introducing important errors.

In Table 1 the approximate values for $\Phi(\sigma)$ are shown in comparison with those given by Wagner, which are assertedly correct in the first four digits for $0 \leqq \sigma \leqq 10$. For large values of σ Wagner's calculations are not accurate, since his curve tends to a false asymptote.

TABLE 1
Approximations to Φ

σ	Wagner	Eq. (43)	Eq. (44)
0	1/2	1/2	1/2
1/2	0.4443	0.4446	0.444
1	0.3994	0.4008	0.398
2	0.3307	0.3307	0.329
4	0.2418	..	0.242
10	0.1255	..	0.114
20	0.0679	..	0.029

The approximations given in Eqs. (43) and (44) will be used in the application of the next section.

VI. Application to the Case of a Sharp-Edged Gust

The results of the preceding section may be applied to the problem of a flat-plate airfoil entering a sharp-edged vertical gust. The flow in this case is not a potential one because the gust boundary itself constitutes a vortex sheet. It will be assumed that in spite of this fact the thin-airfoil theory can be applied to the calculation of the quasi-steady quantities $\gamma_0(x)$ and Γ_0. This corresponds to the assumption that the principle of superposition of flow patterns is applicable. Strictly speaking, this is only the case for potential motions; however, the method yields results which are probably sufficiently exact in the present case, provided that all additional velocities are small so that the deformation of the vortex sheet can be neglected.

Suppose that the leading edge of the airfoil reaches the gust boundary at the instant $t = 0$. Then at the time, t, the relative transverse velocity is equal to V (cf. Fig. 7) between $x = -1$ and $x = -1 + Ut$, and it is equal to zero for $x > -1 + Ut$. The vorticity distribution $\gamma_0(x)$ produced by these velocities is the same as that of the broken-line airfoil represented in Fig. 7 in a parallel stream. Applying the equations of the thin-airfoil theory to this case (see reference 2, Chapter 2), the following formulae are obtained:

$$\gamma_0(x,t) = \frac{\Gamma_0}{\pi \sin\theta} + \sum_{k=1}^{\infty} a_k \frac{\cos k\theta}{\sin\theta} \tag{45}$$

where $\cos\theta = x$ and

$$a_k = -\frac{4V}{\pi} \int_{\cos^{-1}(Ut-1)}^{\pi} \sin\theta \sin k\theta \, d\theta \tag{46}$$

and

$$\Gamma_0(t) = 2V[\cos^{-1}(1 - Ut) - \sqrt{2Ut - U^2t^2}] \tag{47}$$

These formulae apply to the interval $0 \leqq Ut \leqq 2$ during which the airfoil crosses the boundary of the gust. For $Ut > 2$ the airfoil is entirely within the gust, the transverse velocity is constant, and $\Gamma_0 = 2\pi V$ and $\gamma_0(x) = (\Gamma_0/\pi)\sqrt{1-x}/\sqrt{1+x}$, both independent of the time. The two ranges are now considered separately:

(a) $0 \leqq Ut \leqq 2$

The apparent-mass terms are readily obtained using Eqs. (45–47). The integrals are

$$\int_{-1}^{1} \gamma_0(x)x\,dx = \pi a_1/2 = - V[\cos^{-1}(1 - Ut) + (Ut - 1)\sqrt{2Ut - U^2t^2}] \tag{48}$$

$$\int_{-1}^{1} \gamma_0(x)(x^2 - {}^1/_2)dx = \pi a_2/4 = 2V(2Ut - U^2t^2)^{3/2}/3 \tag{49}$$

Hence, from Eqs. (47) and (48), the sum of the first two terms of the lift, Eq. (16a), is

$$L_1 + L_0 = -\rho(d/dt)\int_{-1}^{1} \gamma_0(x)x\,dx + \rho U\Gamma_0 = 2\rho UV\cos^{-1}(1 - Ut) \tag{50}$$

and, from Eqs. (48) and (49), the sum of the first two terms of the moment, Eq. (20), is

$$M_1 + M_0 = -(\rho/2)(d/dt)\int_{-1}^{1} \gamma_1(x)[x^2 - ({}^1/_2)]dx + \rho U\int_{-1}^{1} \gamma_0(x)x\,dx = -\rho UV\cos^{-1}(1 - Ut) \tag{51}$$

It is seen immediately that $M_0 + M_1 = -(L_0 + L_1)/2$, and since it has already been proved that $M_2 =$

$-L_2/2$, this means that the total lift acts at the forward quarter-chord ($x = -1/2$) at every instant. This result was predicted by Küssner[4] and verified experimentally by him,[6] but he was unable to prove it theoretically because of an error in his fundamental equation for waves progressing over the airfoil. Because of an error in sign (see reference 4, page 420, Eq. (60)), these disturbances move over his airfoil from rear to front, which, of course, confuses the results.

The calculation of L_2 is carried out by introducing Φ from Eq. (43) and $\Gamma_0(t)$ from Eq. (47) into Eq. (42). This leads to the elementary integrals

$$\int_0^{Ut} \sqrt{(\tau/2 - \tau)}\, \tau^n d\tau \text{ for } n = 0, 1, 2, \text{ and } 3$$

Hence L_2 is easily calculated, and when the result is combined with $L_0 + L_1$ from Eq. (50) the total lift becomes

$$L = 2\rho UV\{[0.2103 + 0.2603(Ut) - 0.0562(Ut)^2 + 0.0055(Ut)^3]\cos^{-1}(1 - Ut) + [0.7897 - 0.1637(Ut) + 0.0247(Ut)^2 - 0.0014(Ut)^3]\sqrt{2Ut - U^2t^2}\} \quad (52)$$

where $0 \leqq \cos^{-1}(1 - Ut) \leqq \pi$. The result, Eq. (52), is plotted in Fig. 8.

(*b*) *Ut > 2*

In this regime, since the airfoil is subjected to a constant transverse velocity, V, it is seen immediately that $L_1 = M_1 = 0$, $L_0 = 2\pi\rho UV$, and $M_0 = -L_0/2$. Hence the lift again acts at the quarter-chord point. In the calculation of L_2 by means of Eq. (42) the function Φ is taken from Eq. (44) and the value of $\Gamma_0'(\tau)$ is that obtained from Eq. (47) for $0 \leqq Ut \leqq 2$ and is equal to zero for greater values of Ut. Hence the integrals which arise in this case are the following:

$$\int_0^2 \sqrt{(\tau/2 - \tau)}\, e^{a\tau} d\tau = \pi e^a\{I_0(a) + I_1(a)\}$$

and

$$\int_0^2 \sqrt{(\tau/2 - \tau)}\, e^{a\tau}\tau d\tau = \pi e^a\{2I_0(a) + [2 - (1/a)]I_1(a)\}$$

where $I_n(a)$ is a modified Bessel function of the first kind (see reference 3, page 46), and the exponent a has the values ($1/2$) and 0.185. The total lift in this range is $L_0 + L_2$, which finally becomes

$$L = 2\pi\rho UV\{1 - 0.3304e^{-(Ut-1)/2} - (0.1917 + 0.0510t)e^{-0.185(Ut-1)}\} \quad (53)$$

This result is also plotted in Fig. 8. It is seen that the lift on the airfoil increases rapidly after the entrance of the leading edge into the gust ($Ut = 0$), and is equal to 55 percent of its final value when the trailing edge reaches the gust boundary ($Ut = 2$). The increase then becomes progressively slower, and when the leading edge has progressed five chord-lengths into the gust ($Ut = 10$) the lift is 86 percent of its final value.

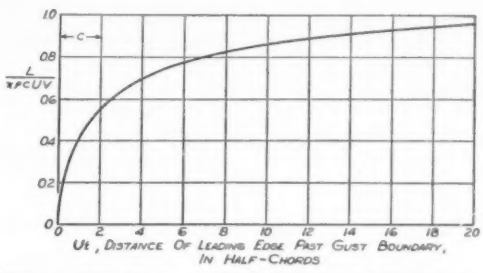

FIG. 8. The lift on an airfoil during and following its entrance into a sharp-edged gust. (Airfoil chord = c.)

Thus, for a wing of chord equal to 20 ft., flying at 200 m.p.h., the lift would reach 55 percent of its final value in 0.07 sec. and 86 percent of its final value in 0.34 sec.

It is known that the vertical gusts which actually occur in the atmosphere are not exactly sharp edged, but consist of a smooth, although rapid, transition of vertical velocity. The rate of increase of lift on an airfoil entering such a smoothly-graded gust can easily be calculated by integrating the effects of a sequence of infinitesimal sharp gusts, using the curve of Fig. 8 for the response of the wing to a sharp gust of unit intensity. A useful graphical method of carrying out such a calculation is given in reference 7. It is obvious that the lift will always act at the quarter-chord point, regardless of the shape of the gust.

The most important effects which have been neglected in the present section, in addition to the effects of finite span, are those resulting from the elastic deflections of the wing and the motion of the airplane as a whole (due to its stability) after entering the gust. Calculations including both effects, but using Wagner's elementary function, $1 - \Phi$, for the rate of build-up of lift (*i.e.*, neglecting the fact that the entire chord does not strike the gust boundary at once), have been published in reference 8. The results of the present paper now provide a better foundation for such calculations.

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(*Additional references on next page*)

[6] Küssner, H. G., *Untersuchung der Bewegung einer Platte beim Eintritt in eine Strahlgrenze*, Luftfahrtforschung, Bd. 13, page 425, 1936.

[7] Jones, R. T., *Calculation of the Motion of an Airplane under the Influence of Irregular Disturbances*, Journal of the Aeronautical Sciences, Vol. 3, No. 12, page 419, October, 1936.

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[10] Glauert, H., *The Force and Moment on an Oscillating Aerofoil*, British A.R.C., R. & M. No. 1242, 1929.

Letters to the Editor

June 26, 1938

Dear Sir:

In the June, 1938, issue of the Journal of the Aeronautical Sciences, Richard C. Molloy presented a paper entitled "A Study of Available Flap Data." As the paper states, it is true that as among the usual types of flap there is little to be gained in $C_{L_{max.}}$ where the flap chord exceeds 20 percent. But this is not true for the Fowler flap where $\Delta C_{L_{max.}}$ reaches 1.70 for a 40 percent chord on a 23012 or a Clark Y airfoil, the flap angle being 30°. For 40° this value rises to 1.80.

Furthermore, scale effect does exist with the Fowler flap and is undoubtedly due to the gap inherent with this device.

All tests conducted by the N.A.C.A. to date show that for take-off purposes the Fowler flap is also the best because the maximum lift can be used and the L/D ratio is higher than for any other type of flap. The most spectacular proof of this is demonstrated by the Lockheed 14.

It is felt that Mr. Molloy has not presented the true story of flaps, nor is the subject so devoid of facts as he would lead the uninformed reader to believe.

HARLAN D. FOWLER

June 7, 1938

Dear Sir:

I have read with interest Richard H. Smith's paper "Laminar Boundary Layer Based on a Minimum Theorem," published in the May, 1938, issue of the Journal of the Aeronautical Sciences, but I must remark that the statement in the footnote to p. 271, that the Blasius profile is out of balance with respect to force or energy or both, cannot be true. The Blasius profile is obtained by an exact solution of the system of equations:

$$\rho[u\ (\partial u/\partial x) + v\ (\partial u/\partial y)] = \mu\ (\partial^2 u/\partial y^2) \tag{1}$$

$$(\partial u/\partial x) + (\partial v/\partial y) = 0 \tag{2}$$

u representing here what is called the "complementary velocity" u' by Mr. Smith.

From (1) the following relations can be deduced (by applying partial integrations):

$$(a)\ \mu\left(\frac{\partial u}{\partial y}\right)_{y=0} = -\mu\int_0^\infty \frac{\partial^2 u}{\partial y^2}\,dy = -\int_0^\infty \rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right)dy$$

$$= -2\int_0^\infty \rho u(\partial u/\partial x)dy - \rho U v_\infty \tag{3}$$

$$(b)\ \mu\int_0^\infty \left(\frac{\partial u}{\partial y}\right)^2 dy = -\mu\int_0^\infty u\frac{\partial^2 u}{\partial y^2}\,dy =$$

$$-\int_0^\infty \rho\left(u^2\frac{\partial u}{\partial x} + uv\frac{\partial u}{\partial y}\right)dy$$

$$= -\int_0^\infty (3/2)\rho u^2(\partial u/\partial x)dy - (\rho/2)U^2 v_\infty \tag{4}$$

When these results are substituted into the equations of momentum and of energy, respectively:

$$\frac{d}{dx}\int_0^\infty \rho u^2 dy - \rho U\frac{d}{dx}\int_0^\infty u dy = -\mu\left(\frac{\partial u}{\partial y}\right)_{y=0} \tag{5}$$

$$\frac{d}{dx}\int_0^\infty \frac{\rho}{2}u^3 dy - \frac{\rho}{2}U^2\frac{d}{dx}\int_0^\infty u dy = -\mu\int_0^\infty \left(\frac{\partial u}{\partial y}\right)^2 dy \tag{6}$$

and when it is noticed that: $\int_0^\infty (\partial u/\partial x)dy = -v_\infty$ then it will be seen that both of them are satisfied completely.

The fact that Blasius' profile is a particular solution of Eqs. (1) and (2), obtained by assuming u to be a function of $y/\sqrt{x}$ only, is of no weight in this connection, so long as it is an exact solution. It can be expected on the other hand that expressions which represent more or less satisfactory numerical approximations to this solution, will not exactly fulfill the equations of momentum and of energy, the discrepancy being dependent upon the margin of inaccuracy tolerated in the expressions used.

In connection with this remark it would appear to the undersigned that the considerations developed by Mr. Smith on the origin of turbulence as due to a failure of balance in the energy relations (p. 270, first column) do not appear convincing.

Moreover, the application of the term "separation profile," etc., to the case of boundary layer flow under constant pressure, would give rise to questions.

J. M. BURGERS
Technische Hoogeschool
Delft, Holland

July 12, 1938

Dear Sir:

In a footnote in my recent paper "Laminar Boundary Layer Based on a Minimum Theorem," published in the May, 1938, issue of the Journal of the Aeronautical Sciences, I gave some figures which I computed a few years ago which indicated that the Blasius' velocity profile is out of balance with respect to energy. In a letter from Dr. Burgers at Delft, which appears also in this issue, he shows beautifully and correctly that this conclusion cannot be correct. After agreeing with Burgers' proof, I have made a complete re-examination of the Blasius' development with a view to discovering the discrepancy in my early computations. This analysis, just completed, shows that the Blasius' velocity profile is in force and energy balance, as Dr. Burgers shows it should be, provided one takes as the layer thickness factor the theoretical value $R_x^{1/2}(\delta/x) = 6.28$ as found in the new analysis, instead of the value 4.5 or thereabouts, which has been commonly accepted and which was used in my early computations for energy balance.

I wish, therefore, to retract the remark in the footnote cited that the Blasius profile is unbalanced with respect to energy and replace it with the above statement. Also I wish to thank the Editor for giving me an opportunity to read Dr. Burgers' letter before its publication and to prepare an answer that could appear with it.

R. H. SMITH
Massachusetts Institute of Technology

Plastics as Structural Materials for Aircraft[1]

GORDON M. KLINE, *National Bureau of Standards*

Presented at the Structures Session, Sixth Annual Meeting, I. Ae. S.
January 24, 1938

PLASTICS and aircraft have undergone their major development during the past twenty years. Both are industries in which many optimistic predictions for a generation of progress have become realities within two to five years. Currently, efforts are under way in England and Germany to link more closely these two relatively new and expanding industries by utilizing plastic materials for the construction of aircraft. Admittedly this is a development the realization of which would appear to require many years of experimental research on materials and fabrication problems. However, noteworthy progress has already been accomplished by Kraemer[2] in the German Aeronautical Institute, by de Bruyne[3] and his associates in the laboratory of Aero Research, Limited, and by de Havilland,[4] King, and Walker of the de Havilland Aircraft Company. The work of these and other investigators[5] is summarized in this paper.

Most of the experimental work on the use of plastics in aircraft construction has been with the phenol-formaldehyde resin type, known in this country by such trade names as "Bakelite" and "Durez." This material is the least expensive of the synthetic resins and is thermosetting, *i.e.*, it cures during the molding process to an infusible, insoluble mass. The thermoplastic materials, such as the cellulose derivatives, and vinyl and acrylic resins, which can be alternately fused and hardened by raising and lowering the temperature, are probably too liable to cold flow to be useful as structural materials.

Phenolic plastics are usually made up of two distinct ingredients, the resinous binder and a reinforcing agent. The raw materials for the resin are generally formaldehyde and phenol (also known as carbolic acid) or technical cresol. Phenol, like cresol, is obtained as a by-product of the coal distillation industry, or it is prepared synthetically by processes such as the alkaline hydrolysis of chlorobenzene. Formaldehyde, which is normally a gas, is made by the catalytic oxidation of methyl alcohol. Furfural, an aldehyde which can be obtained from various natural sources, for example, oat hulls, cornstalks, and the like by distillation with acid, is sometimes substituted for the formaldehyde. The selection of a reinforcing material and its incorporation into the composition in such a manner as to utilize to a maximum its capabilities, has been the subject of considerable investigation already and will continue to claim the attention of workers in this field. In the usual molding composition the resins are mixed with ground or shredded fibrous fillers, such as wood flour, cotton flock, or comminuted canvas. These fibrous materials not only reduce the cost of the plastic, but also improve its mechanical properties, particularly with regard to tensile and impact strength. Plastics of greater mechanical strength are produced by employing paper or cloth as the reinforcing medium. These laminated materials are prepared by impregnating the sheets with a solution of the resin while it is still in a soluble state, drying, and then bonding many layers together by the application of heat and pressure. This treatment converts the resin to the infusible, insoluble state and yields a hard, dense product which will not delaminate and possesses excellent mechanical strength and weathering resistance. Phenolic laminated materials of this type have already found many applications in the aircraft, automotive, railroad, telephone, power, and building industries.

Recently two other types of reinforcing materials have been investigated with particular reference to their employment in plastics for aircraft construction. Kraemer[2] observed that products superior to the paper- or cloth-laminated type in certain physical properties, especially modulus of elasticity in both tension and compression, could be prepared by impregnating extremely thin wood veneers of 0.1 to 0.3 mm. (0.004 to 0.012 in.) thickness with resin and forming them into a multi-layered cured sheet in the usual manner. Better strength properties were obtained by laying every tenth veneer with the grain of the wood at right angles to the principal grain direction than by pressing the veneers together with all grain directions parallel. De Bruyne[3] has worked primarily with cord or long fiber reinforcing agents in order to obtain maximum tensile strength, incorporating only the minimum amount of resin required to bind these fibers together. The tensile strength of various fibers which could be used for this purpose are shown in Table 1. By subjecting the fibers to an initial stress during the process of molding, a considerable increase in the modulus of elasticity in tension is obtained. However, this kind of reinforcement has very little effect on the ultimate compressive strength which remains about the same as for the pure resin. Similar results with fibers of agave, sisal, and aloe have been reported by Riechers.[6]

TABLE 1

Tensile Strengths of Various Fibers

Material	Tensile Strength Lb./Sq. In.	Specific Gravity	Maximum Ratio of Tensile Strength to Specific Gravity Lb./Sq. In.
Cotton	40,000– 62,000	1.55	40,000
Hemp	114,000–131,000	1.48	89,000
Ramie	99,000–114,000	1.52	75,000
Flax	85,000–156,000	1.46	107,000
Silk	50,000– 63,000	1.36	46,000

Some of the physical properties of these various types of plastics which are pertinent to their use as structural materials for aircraft are summarized in Table 2 from various publications. Similar data reported in the literature for the materials which have been employed for fabricating aircraft, namely, high tensile steels, aluminum and magnesium alloys, aircraft spruce, and birch plywood, are quoted for purposes of comparison.[7]

DENSITY

It will be noted in Table 2 that the specific gravities of the reinforced plastics are greater than those of spruce and plywood but are considerably less than for the metals. The advantage of low-density materials in permitting thicker wall structures is considered in detail by Shanley[8] and by de Bruyne.[3] Tuckerman[9] states that for a given modulus-density ratio "the wall with the greater thickness will have somewhat greater stability. Where the use of the heavier material would require extremely thin walls, there is a very certain advantage, but of uncertain and variable magnitude, in the use of thicker walls of lighter materials, in some cases even with a somewhat smaller modulus-density ratio."

STATIC STRENGTH

The comparative tensile and compressive strengths and ratios of strength to specific gravity of the aircraft materials and plastics are shown in Table 2. Although the values for the strength of the plastics are less than for steel and aluminum alloy, they are equal to or greater than for spruce which is used for structural members of aircraft. The tensile strength-weight ratios of the ordinary laminated phenolic products (paper or fabric reinforcement) are less than those for steel, aluminum alloy, and wood, but the phenolic products with cord or wood reinforcement compare favorably with these accepted constructional materials. The compressive strength-weight ratios of the plastics are of the same order as those of the metals.

MODULUS OF ELASTICITY

In many cases the component members of an aircraft will fail by instability due to buckling before the material can develop its full strength in compression. In these instances the strength of the member will generally increase with an increase in the ratio of the modulus of elasticity to the specific gravity of the material, provided the outside dimensions of the member and its weight are unchanged. Average values for the modulus of elasticity in tension and compression and the moduli-density ratios are shown in Table 2.

The conventional types of laminated plastics are characterized by low moduli of elasticity, particularly in compression, and it was realized very early that this lack of stiffness is a major problem in the utilization of reinforced plastics for structural purposes. With reference to metals Tuckerman[9] notes that "Density and modulus of elasticity are stubborn properties of the material. The most violent differences in heat treatment and mechanical working, differences in treatment which change the strength of a material by ratios as great or even greater than 10 to 1 can, at most, cause a change of a few percent in either modulus or density." However, the stiffness of reinforced plastics can be varied over a wide range by differences in the type of reinforcement used and in the pressure applied in manufacturing the plastic. Cord reinforcement is much superior to paper or fabric filler if increased tensile strength and Young's modulus in tension are desired. On the other hand, wood veneer reinforcement gives higher values for the modulus of elasticity in compression than the other types of fillers investigated, and according to King[10] is much to be preferred for main structural members. However, according to the latter investigator, the more lightly loaded parts of aircraft structures do not require a material of great ultimate strength but rather one which is self-stabilized over large areas and capable of taking moderate loads without premature waving. He reports the development of a light composite sandwich material produced by binding resin-sprayed facings to a central low-density core (closed-pore sponge rubber) which acts almost entirely as a means of support and so enables the skin to develop loads approximating the ultimate strength of the material employed.

The usual reaction to the problem of increasing the stiffness of the plastics is the thought that metal mesh, rod, or wire should provide a satisfactory reinforcing medium. It is rather surprising to find that data on the properties of such products are lacking. King[10] notes that "the proposal to use wire reinforcement near the top and bottom surfaces of beam members certainly deserves very careful consideration. If the designer is disposed to allow some additional weight in order to attain greater beam stiffness, the twin problems of slip and unequal expansion still remain to be solved. As regards the first of these, much depends on the size of wire and rate at which the load builds up in the reinforcement by shear transference from the surrounding mass of resin. Other things being equal,

TABLE 2

Physical Properties of Reinforced Plastics, Wood and Metals[7]

Material	Specific Gravity	Tensile Strength Lb./ Sq. In.	Ratio of Tensile Strength to Specific Gravity Lb./ Sq. In.	Compressive Strength Lb./ Sq. In.	Ratio of Compressive Strength to Specific Gravity Lb./ Sq. In.	Modulus of Elasticity in Tension (E_t) Lb./ Sq. In.	Ratio of E_t to Specific Gravity Lb./ Sq. In.	Modulus of Elasticity in Compression (E_c) Lb./ Sq. In.	Ratio of E_c to Specific Gravity Lb./ Sq. In.
Stainless steel (18–8)	7.85	185,000	23,600	150,000[a]	19,100	30,000,000	3,800,000	30,000,000	3,800,000
Chrome molybdenum steel (heat-treated)	7.85	180,000	22,900	150,000[a]	19,100	29,000,000	3,700,000	29,000,000	3,700,000
Aluminum alloy (24-ST)	2.80	62,000	22,100	40,000[a]	14,300	10,400,000	3,700,000	10,400,000	3,700,000
Magnesium alloy (Am58S)	1.81	46,000	25,400	35,000[b]	19,300	6,500,000	3,600,000	6,500,000	3,600,000
Aircraft spruce (Douglas fir)	0.43	10,000	23,300	5,000	11,600	1,300,000	3,000,000	1,300,000	3,000,000
Birch plywood	0.80	13,100	16,400	5,700	7,100	1,400,000	1,800,000		
Birch-reinforced resin	1.27	27,700	21,800	22,800	18,000	3,400,000	2,700,000	2,300,000	1,800,000
Paper-reinforced resin	1.37	19,000	14,000	30,000	22,000	1,200,000	900,000	600,000	400,000
Fabric-reinforced resin	1.37	10,000	7,200	40,000	29,000	1,000,000	700,000	600,000	400,000
Cord-reinforced resin	1.37	25,000	18,700	27,000	20,100	5,900,000	4,300,000	600,000	400,000

[a] Yield point in compression.
[b] Yield point in tension. Yield point in compression is substantially equal to yield point in tension for wrought alloys.

greater strength would be obtained by the use of a large number of very thin reinforcing filaments rather than by using a few thick ones, for obviously the surface cross-sectional area ratio would be greater and consequently a better shear linkage would be attained. The loosening of the bond between the resin and reinforcement, on account of unequal expansion, is a matter requiring some consideration. The coefficient of lineal expansion of synthetic resin is approximately four times that for steel, but supposing the former 'shrunk' onto the reinforcement, this difference of expansion may not be serious over the small temperature range which is likely to occur in practice." It has also been pointed out by Walker[11] that there is good reason for avoiding, if possible, metal reinforcement because its use would introduce into the material the poor fatigue properties of crystalline matter.

The moduli of elasticity of the various structural materials have been compared in Table 2 on the basis of the modulus-density ratios. De Bruyne[3] points out, however, that this is not an entirely satisfactory basis for the comparison of their relative suitability for various aircraft members, because stiffness involves constants characteristic not only of the material but also of the geometrical features of the structure. For example, in computations on the stiffness in stressed-skin construction, it is not (E/specific gravity) but rather the magnitude ($\sqrt[3]{E}$/specific gravity) that is of chief significance. Thus, for many purposes a low density is more important than a high modulus of elasticity, which makes the comparison of the stiffnesses of the metals and reinforced plastics more favorable than would be apparent from Table 2.

RESISTANCE TO LONG-TIME LOADING

The reinforced plastics have been found to be comparable to wood in their resistance to long-time loading. Experiments performed by the de Havilland Aircraft Company and reported by de Bruyne[3] showed that the endurance limit in tension of cord-reinforced plastic to continuous loading is approximately 75 percent of the strength under instantaneous loading. Graf[12] found that the static endurance of pine is about 60 percent of the strength as measured by short-time test.

ENDURANCE LIMIT FOR ALTERNATING LOADS

The endurance limit of fabric-reinforced plastic as determined by rotating beam tests is about 60 percent of the instantaneous static strength according to tests made by Gough and Cockcroft and reported by de Bruyne[3]; the limit observed by Kraemer[2] is only about 35 to 40 percent of the static strength. Parzich[13] found the torsional endurance limit to be 50 ± 10 percent of the static torsional strength. Riechers[6] discusses continuous bending tests of plastics in some detail and notes that more recent tests at the Technical School at Darmstadt gave endurance limits of 25 to 35 percent of the static tensile strength. De Bruyne[3] notes that the behavior of reinforced plastics in such tests is very different from that of metals because the specimen may continue to hold together for many millions of revolutions after a split has first appeared. The amorphous character of the material seems to prevent any violently progressive crack formation.

STRENGTH UNDER REPEATED IMPACT

De Bruyne[3] compared the behavior of specimens of

TABLE 3

Energy Absorption in Torsional Oscillation
(Data from de Bruyne and Maas[14] and Iobike and Sakai[15])

Material	Strain Energy Absorbed Percent per Cycle
Fabric-reinforced resin	24
Cord-reinforced resin	20
Paper-reinforced resin	18
Walnut	12
Zinc	12
Aluminum	1.10
Steel (0.55% carbon)	0.24
Steel (0.9% carbon)	0.17
Nickel	0.021

the same size and shape of a cord-reinforced phenolic plastic and various alloys under repeated impact tensile loads, using an Amsler repeated impact testing machine. The strength values obtained for the plastic were quite comparable to those for the metals and indicated the ability of the cord-reinforced resin to resist shock.

Energy Absorption

Measurements of the energy absorbed under torsional oscillation of various materials have been made by de Bruyne and Maas[14] and by Iobike and Sakai.[15] The results of these two investigations are summarized in Table 3. The ability of plastics to absorb energy would be of advantage in airplane construction in that undesirable and often dangerous resonance vibrations would be suppressed. Materials of high energy absorption may also be expected to resist impact better than those of low damping property since the energy of the blow can be used up not only in creating strain energy in the material but also in overcoming the internal friction. A material of high damping capacity is less sensitive to the effect of surface notches or sudden changes in cross-section than a material with a small energy absorption. A disadvantage of excessive damping is the considerable internal heating which may occur and which should be investigated in particular for materials intended for use as propellers.

Flexural, Shear, and Torsional Strengths

Kraemer[2] made a detailed examination of the flexural, shear, and torsional strengths of various reinforced resins, wood, and plywood, with particular reference to direction of application of the stress relative to the principal fiber axis. The effects of variations in the thickness of the veneers, grain directions in the various layers, and the amount of compression of the wood were also investigated.

Corrosion

The resistance of reinforced plastics to corrosion has been an important factor in promoting their extensive use for many industrial purposes. Kraemer[2] made a series of tests with phenolic resin products reinforced with paper and fabric. In aging tests out-of-doors, specimens of the fabric-filled material had undergone practically no loss in strength after 15 months. Thin paper-filled specimens 1 millimeter thick had frayed at the edges and showed a reduction in strength of 14 percent after 15 months. The originally smooth surface of the majority of the specimens had become matt after 6 months. Tests indicated that the flexibility of the specimens was not affected by exposure for 15 months. The resistance to salt water was determined by immersion for 8 months in a stirred 3-percent solution of common salt. Strength tests after 8 months showed that the paper-filled product had lost 12 percent of its original strength but that the fabric-filled material remained unchanged. There was practically no change in the appearance of the surfaces after being immersed in the salt solution for 8 months. Gasoline and oil had a negligible effect on the appearance and strength properties of plastics after a 10-day period of immersion. The maximum water absorption noted for a 24-hour period of immersion was 0.85 percent for paper-filled specimens. The reinforced phenolic plastics are difficult to ignite, and once ignited, burn relatively slowly and are readily extinguished by a slight draft. No results of tests on the stress corrosion of plastics have been reported, but it is probable that this effect is far less serious than for metals.

Fabrication

Four methods of joining various sections made of reinforced phenolic material have been suggested, namely, cementing, riveting, bolting, and keying by interlocking joints. The synthetic resin cements have better aging properties and moisture resistance than the protein glues heretofore employed by the aircraft industry. Joints can be made between laminated phenolic resin plastics that will have a strength of 2000 pounds per square inch or more, in shear. Greater strength may be achieved if the surface of the plastic is etched or sand-blasted so as to expose the fibrous reinforcing material to the action of the cement. With respect to the feasibility of riveting and bolting structures made up of reinforced phenolic plastic, de Bruyne[3] has reported values for the bearing strength of the cord-filled product. These are given in Table 4.

In general, the bearing strength of this material is more than five times that of spruce loaded parallel to the grain and thirty times that of spruce loaded perpendicular to the grain. Another factor involved in making riveted or bolted connections is the shearing strength. The low shearing strength of wood requires a large separation between the bolts. The greater shearing strength of the reinforced plastics permits a much closer spacing of the bolts. The method of keying by the use of interlocking joints has been used in metal aircraft construction and should also be applicable to structures made from reinforced resinous products.

TABLE 4

Diameter of Bolt Inch	Bearing Strength Lb./Sq. In.
3/8	26,300
5/16	29,400
1/4	31,500
3/16	37,000

RESEARCH PROBLEMS

The exploration of the potential applications of reinforced plastics to aircraft construction is in its infancy, and is still uncharted. Research in this field must include problems relating to: the choice of resin and reinforcing material; the method of combining and forming them into a suitable product; the testing of such products to determine whether they possess the requisite physical characteristics; the design of structural members to take full advantage of the properties and fabrication possibilities of plastics; and the equipment for forming the separate sections and the technique of joining these sections to produce the finished aircraft. In the determination of the physical properties, it will be necessary to consider the anisotropic nature of the reinforced materials and to make the measurements along the various axes accordingly.

The stress-strain curve for reinforced resins is dependent on the rate at which the load is applied. When a stress is applied, the strain does not instantaneously reach its maximum value. The magnitude of this "elastic after-effect" increases with the stress. De Bruyne[3] notes that this "after-effect" is largely reversible and becomes very nearly so after the load has been applied and removed four or five times. The irreversible component of the creep becomes more noticeable at high stresses. This property is of prime importance with reference to the use of reinforced phenolics for structural members of aircraft and should be investigated in detail for any materials which may appear to be promising in other respects. It is also to be expected that the creep, endurance limit, damping, impact strength, and other properties of the phenolic reinforced plastics will vary somewhat with temperature. Therefore, the behavior of these materials should be studied at various temperatures within the range which might be expected to be encountered in service.

PRESENT OUTLOOK FOR COMMERCIAL APPLICATIONS

In the fabrication of aircraft today the labor costs are high relative to the costs of tools. If large sections could be molded in one piece, the labor costs would be reduced but the costs of the molds and presses would be very high. Such a change in type of construction would not be economically practicable except in the mass production of aircraft of a standard design. Langley[16] suggests, therefore, that progress in the utilization of plastics in aircraft construction will be made by the gradual introduction of these materials into an otherwise orthodox structure, and that the early stages of this development will involve the molding of such small units as fins and rudders and the fabrication of the larger units from reinforced sheets and molded sections by conventional methods of jointing. Controllable pitch propeller blades have been made from reinforced plastics in this country[17] and are currently being manufactured in Germany and England. An airplane in which the wings and fuselage were each molded in one piece of extremely thin laminated films of wood and cellulose acetate was designed and built by Atwood[18] and successfully flown. But this type of material is not believed to be suitable for general use in aircraft construction because plastics made with cellulose acetate are subject to cold flow under low loads and to considerable variation in moisture content at different humidities, resulting in excessive dimensional changes and warping. De Bruyne[3] has presented in some detail theoretical considerations pertaining to the application of reinforced phenolic plastics for various structural parts of aircraft, such as spars, cowlings, struts, and covering. However, until more information is available on the problem of combining resin and reinforcing agent in such manner as to obtain requisite strength and stiffness and until such products have been thoroughly tested to determine their behavior under repeated stresses, it is too early to expect to make any considerable progress on the design and fabricating problems.

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Book Reviews

What About the Airship?,* by COMMANDER C. E. ROSENDAHL, Charles Scribner, New York; 431 pages, $3.50.

It is with great disappointment that we put down "What About the Airship?" after a careful reading with a conscientious intent to give the airship a fair hearing particularly from what we hoped would be a competent and sensible source of the highest experience.

Instead, we found that omissions, errors, and deliberately misleading comparisons make Commander Rosendahl's exposition and pleading on behalf of airships of lighter-than-air type so obviously a piece of biased propaganda against the airplane that its value in advancing the cause of the airship is seriously to be questioned.

Nowhere in the index could one find a single mention of strength or structure. Nowhere in the book is there an enlightening discussion of the major worry of all engineers (including the Durand Committee) that the real trouble with rigid airships of large size is structural weakness—due to lack of engineering foundation for the proper computation of gust loads. The technique of "storm evasion" declared by Dr. Eckener to be so essential in airship operation is lightly passed over. There are no adequate figures on the cost of helium filled commercial dirigible operations. We had hoped for some new ones to fill a disheartening gap for the making of proper estimates. The essential elements of a water-recovery system and the relation thereto of the choice of gasoline engines that facilitate this, as against Diesel engines which are more difficult, are practically ignored.

In estimates of airship range the very necessary concept of considering "air miles" is completely ignored, and yet in such places as the Caribbean, where forty or fifty mile headwinds for days on end are by no means unusual, computations on cruising speed over the ground instead of the air are of doubtful validity.

Picturing the pilot aboard one of to-day's heavier than aircraft as "flying continuously for sixteen to twenty-four hours" (page 172) Comdr. Rosendahl goes on to say "his sense of balance and his mental processes must never relax for an instant. His hearing is occupied with radio. . .his eyes must constantly rove over a multitude of instruments, scan the sky for weather and the surface for emergency landing features. . . . Nearly every one of his senses must be one hundred percent on the job continuously." To any layman who has sat in the pilot compartment of a "Clipper" this description happens to be in error. Due to the Sperry automatic control mechanism used, the pilot relaxes and converses readily. He is not looking for "Emergency" landing features over the ocean, his radio operator is handling radio and occasionally may give him a written memo., his engineer is watching practically all the engine instruments, very few of which are on the pilot's dash-board and among his senses "one hundred percent on the job," would have to be his sense of humor, on reading such tripe.

The best section of the book is that on the naval uses of airships, but it is impossible in a review to discuss many of these sections without getting into a long argument of airplanes against airships.

However, when we get through with the perusal of this work there is the inescapable conviction that it is 431 pages of alibi which is unfortunate because there are many standpoints from which the airship still has merit. When, to support that merit, it is necessary for its proponents to bring out a parade of arguments against the airplane (which is doing pretty well throughout the world despite its obvious dangers and shortcomings) and then add to that a sob story involving cries of sabotage, unfair treatment, hidden politics, and the usual disgruntled inventor psychology of being militated against by hidden and sinister forces, one can only put the book down with a feeling that perhaps after all lighter-than-air is not so easy to defend.

And in conclusion the aeronautical student might pause to consider that the airship in 30 years has progressed from 50 miles an hour to only 80 miles an hour—while the airplane in much less time has progressed from 50 miles an hour to 440.

GROVER LOENING

Life, Heat, and Altitude, by DAVID BRUCE DILL, Harvard University Press, Cambridge, 1938; 211 pages, $2.50.

The author of "Life, Heat, and Altitude" has directed the greater part of his professional career to investigations of the human body under various conditions of high temperatures and great altitudes and is considered the outstanding authority in those fields. His present book is concerned with the bodily changes which take place in order that the organism may adapt itself and survive in hot dry deserts, in hot humid tropics, and in the cold thin air of high altitudes.

The first half of the book is devoted to life in hot climates, and such prosaic sounding topics as energy exchange, oxygen supply, perspiration, and thirst are dealt with in a manner which should fascinate the average reader.

For those interested in aeronautics, the latter half of the book should prove to be of particular value, for here the problems of life at high altitude are discussed in detail. The last chapter is devoted exclusively to high altitude flight and summarizes briefly the information now available in this field of medical knowledge.

The literary style employed in this book is most ingenious, in that highly technical material has been presented in a manner which will appeal to the layman and scientist alike. The book is recommended both for the technical information presented and as an interesting account of the living organism under stress.

HARRY G. ARMSTRONG
Wright Field

* It is obvious that the reviewer finds himself in sharp disagreement with a great many of Comdr. Rosendahl's statements. Since the Journal is no place to conduct a detailed controversial discussion, the complete review has been condensed to the introduction and the conclusion. From this the reader may get a fair impression of the reviewer's opinion of the book. *Editor.*

Elementary Principles of Airline Passenger Transportation

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Presented at the Air Transport Session, Sixth Annual Meeting, I. Ae. S.
January 27, 1938

SUMMARY

This paper is an attempt to evaluate the factors which account for the selection of any particular transportation method. In the final analysis, convenience ranks first when the journey is short. Cost comes into the lead as the length of the journey increases with comfort surpassing it in importance for very lengthy journeys. Where time is the major factor, air transportation, when available, ranks first.

THE principles herein laid down are elementary in every respect. In fact, some are so elementary as to have been completely overlooked many times in hearings and utility commission findings concerning the various aspects of passenger transportation. The only discussion that has been seen by the author that considers these principles is in the brief of the Pacific Greyhound Lines by their attorneys, H. C. Lucas and Earl A. Bagby, before the Railway Commission of the State of California in a recent Santa Fé bus application.

Obviously airline passenger transportation is a small division of the passenger transportation business and even the business of passenger transportation is a small part of the total of human transportation. However, to limit the scope of this discussion, it is proposed to restrict consideration to inland transportation and to except inland waterway transportation.

The field of individual transportation can be divided into private and common carrier transportation. Private transportation is of the greatest importance to the individual and has reached its greatest development, by automobile, in the United States. The common carrier is of greatest importance to the commonwealth and has reached a very high state of development in the industrial centers of the world and a somewhat more limited development elsewhere. The private carrier needs but one user to justify it. The common carrier requires a great multiplicity of users.

With the limitations stated, human transportation uses basically three methods: road, rail, and air. Of the three methods, only the road is susceptible to any considerable development in private transportation; air offers a very small field and rail none at all.

Private transportation is not a part of the transportation business as such, but some consideration must be given to its development in order to show the gradually narrowing field of public passenger transportation.

In the last hundred years, private transportation has been one of the greatest single factors in man's economic development, particularly in America. Prior to 1800 the possession of a means of private transportation, the horse, established the importance of the individual. In witness to this it is only necessary to cite that Cavalier, Chevalier, Knight are all synonymous with horsemen, and were the basis of gentry and quality.

Early in the 19th Century the push bicycle was invented which for the first time gave some promise of private transportation without the necessity of considerable personal service to support it. The doctrine of the equality of man vividly expressed in the Declaration of Independence inevitably resulted in a new conception wherein the independence of the individual became an even greater measure of self-importance than the command of personal service. This viewpoint accompanied by the contemporary industrial development, made mechanization of private transportation inevitable. The push bike shortly developed into the high wheel bicycle, which in turn gave way to the safety bike of the last two decades of the 19th Century. The invention of the pneumatic tire added another impetus to the development and a practicable private transportation vehicle for short distances was available. On level, short distance transportation, such as in Europe, it is still adequate but elsewhere something more was needed, such as plural occupancy and power propulsion.

The power-propelled vehicle was not a new thought. Simon Stevin powered one with sails in Holland about the beginning of the 17th Century. Nicholas Cugnot built a steam-powered artillery tractor in France in 1769. Oliver Evans built a combination steamboat and land vehicle in Philadelphia in 1805. Steam carriages and stages were used extensively in England as early as 1810. All of these developments were, however, particularly for public transportation.

Toward the end of the 19th Century the first primitive automobiles appeared and it became apparent almost immediately that the venture was quite different in purpose and concept to the attempts at previously built self-propelled vehicles. First they were of small size, founded on the horse-drawn buggy rather than on the stage coach and were accordingly designed to seat from two to six people. The relative simplicity, lightness, and power of the gasoline internal-combustion engine was of enormous advantage. They developed quite rapidly and by the beginning of the 20th Century

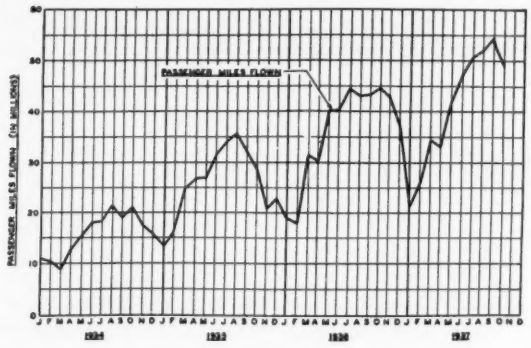

FIG. 1. Passenger miles flown by domestic airlines. (Bureau of Air Commerce.)

CONVENIENCE	MOST IMPORTANT FOR SHORT JOURNEYS EXISTANCE OF PRIVATE VEHICLE USUALLY DECIDES THE QUESTION	PRIVATE TRANSPORTATION MOST CONVENIENT ORDER OF CONVENIENCE OF COMMON CARRIERS 1 HIGHWAY BUS 2 CHAIR CAR TRAINS 3 PULLMAN AND LUXURY TRAINS 4 AIRLINES
COST	MOST IMPORTANT FOR INTERMEDIATE TRIPS PRIVATE CARRIER WILL ORDINARILY FIGURE ONLY IF SEVERAL PERSONS ARE INVOLVED	ORDER OF CHEAPNESS OF ALL CARRIERS (ONE PERSON) 1 HIGHWAY BUS 2 CHAIR CAR TRAINS 3 PRIVATE AUTO (ALL COSTS) 4 PULLMAN TRAINS AND AIRLINES
COMFORT	MOST IMPORTANT FOR EXTENSIVE TRIPS PRIVATE CARRIER WILL ORDINARILY BE CONSIDERED ONLY WHEN MANY PLACES ARE BEING VISITED AND SEVERAL PERSONS ARE INVOLVED.	ORDER OF COMFORT IS LARGELY A MATTER OF OPINION AND TASTE 1 BEST AIRPLANES 2 PULLMAN AND PARLOR CARS 3 ORDINARY AIRPLANES 4 PRIVATE AUTO 5 CHAIR CAR TRAINS 6 HIGHWAY BUS.
SPEED	MOST IMPORTANT WHEN BUSINESS ADVANTAGE WILL ACCRUE OR WHEN AN EMERGENCY EXISTS	AIRLINES ARE, EXCEPT UNDER UNUSUAL CONDITIONS, BY FAR THE FASTEST MEANS OF TRAVEL

FIG. 2. Primary factors—passenger transportation.

were receiving an acceptance which had reached considerable proportions by the end of the first decade. After 1920 personal transportation in the U. S. was overwhelmingly by the private automobile, reaching the extraordinary figure, according to H. E. Hale, of 430 billion passenger miles in 1936 as against considerably less than eighty billion by all means of public transportation put together, including highway buses.

Fig. 1 shows a plot of the growth of airline passenger traffic on the domestic airlines of the United States. During the year 1937, it is estimated that just under one-half billion passenger miles were flown, making air transportation $^{6}/_{10}$ of 1 percent of the total common carrier transportation, excluding street cars and street buses. This is also $5^{1}/_{2}$ percent of the Pullman car transportation. The increasing amplitude of the seasonal fluctuation is somewhat alarming but in any case the increase in business has been fairly steady from year to year.

The primary factors determining the choice of transportation method are convenience, cost, comfort, and speed. These are tabulated in Fig. 2. These are positive factors. Secondary factors are utility, reliability, and safety. These three factors are negative for the reason that their lack vetoes a primary factor. Generally speaking the primary factors are the dominant ones. However, should there be a lack of one of the secondary factors, the primary reason is partly nullified and another choice may result.

In the selection of a mode of transportation the traveler invariably has one dominant reason. In choosing private transportation over public transportation convenience is that reason. If private transportation is available, its convenience is unquestioned and unless the proposed journey is a considerable one, no further consideration is necessary before arriving at a choice. Convenience is the greatest factor in short journeys, gradually losing its importance, however, as the length of journey increases. The extensive trip in the large majority of cases brings cost into a primary position until the journey becomes so long that comfort takes its place as being most important. Even on relatively long journeys, however, it is found that a large percentage of the total travel will be in highway buses and chair cars on the railroads which very definitely stand first when considering cost. In a few cases speed becomes the major factor and when available, air transportation stands first.

Further consideration will be given to the determination of the length of journey but before so doing, it is desirable that the secondary factors be discussed. The secondary factors apply regardless of journey length.

Utility, when it exists, is a part of the convenience factor. It is measured by the capabilities of the transportation method, particularly in regard to the traffic points that can be served. When a transportation vehicle is unable to reach a required destination, it lacks utility so the method is void, or only partially effective. Lack of this particular type of utility may accordingly change the otherwise logical choice. The highest utility is ordinarily available with road transportation and the fewest places are served by air transportation.

Wellington, in his "Economics of Railway Location," shows that other things being equal traffic value varies as $n\ (n-1)/2$ where n is the number of traffic points served. In this same work Wellington also lays considerable stress on the location of passenger terminals, considering it very necessary that they be convenient to business and population centers.

Studies made at the Boeing School of Aeronautics, and by Fortune magazine, indicate that under present conditions a maximum of 40 percent of the existing Pullman car transportation would be all that could be expected to accrue to air transportation were the opportunities for use to be made identical. Fig. 3 shows an application of Wellington's terminal location rule to the airport problem. The lower curve shows 25 percent reduction per mile displacement, estimated by Wellington, which, since his studies were first published in 1887, was obviously based on horse and buggy transportation. Present day surface traffic movement in our larger cities shows little if any improvement over the horse and buggy. Again, studies at the Boeing School indicate that cities having much more than a million population do not develop the air traffic that would be expected from consideration of relative wealth, business, and industrial importance, etc., as they should

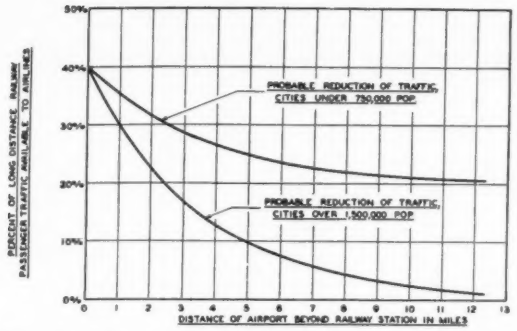
PERCENT OF LONG DISTANCE RAILWAY PASSENGER TRAFFIC AVAILABLE TO AIRLINES
PROBABLE REDUCTION OF TRAFFIC, CITIES UNDER 750,000 POP.
PROBABLE REDUCTION OF TRAFFIC, CITIES OVER 1,500,000 POP.
DISTANCE OF AIRPORT BEYOND RAILWAY STATION IN MILES

FIG. 3. Effect of distance to airport on probable passengers.

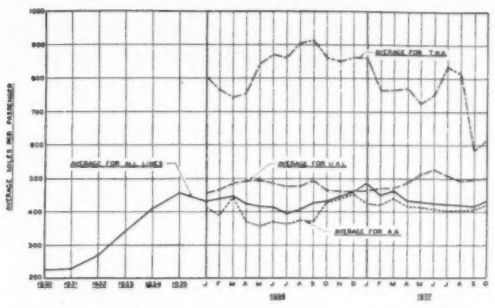

FIG. 4. Length of average air trip—domestic airlines.

were they unhampered by local congestion and other things. The upper curve is an attempt to apply the same rule to cities of a smaller size where a higher percentage of the business now accrues to the air carrier.

The secondary factor, reliability, is somewhat more difficult to define. All traffic is subject to interruption and delay by mechanical failure or interference of the elements. While storm conditions are prevailing air transportation is frequently grounded. However, the after effects of storms, such as floods, washouts, snow, etc. often paralyze highway and railway travel for days or sometimes even weeks in extreme cases. There are times accordingly when air transportation is considerably more reliable than other means and *vice versa*. This factor cannot, then, be applied except specifically.

To the timid, opinions as to safety are of primary importance, overshadowing all else. That opinion and not fact determines, is proved in that private automobile transportation, while overwhelmingly popular, is considerably less safe than any method of public transportation. Each automobilist imagines himself to be perfectly competent. Friends and relatives entrust themselves to his judgment without question. True safety is of minor importance in determining the actual issue.

Air transportation has suffered greatly from the widespread publicity given to even minor air mishaps. This publicity has developed an opinion in the minds of the man in the street and his family that an air journey is a hazardous undertaking. The news value of an air accident is, of course, unquestioned, probably because, as expressed by C. G. Grey of the British magazine "The Aeroplane," "People are not used to being killed by airplanes." The elapse of time and the establishment of positive safety records is the only possible answer to this problem, and it is certain that ways will be found to develop the answer.

It is very probable that the average traveler looks upon the length of trip as being more a matter of time than distance. Any round trip which can be completed within one day, is looked upon as being a short journey. Two or three days' traveling, mostly by daylight, would be considered a moderate journey and an overnight or a longer trip in which the travel was continuous, would be considered a long journey. These classifications, while rather loosely drawn, would describe the American viewpoint. When the time element becomes of business advantage or when the elapsed time on the trip would otherwise be extreme, speed will become, as mentioned earlier, the primary factor.

Short trips necessitate very frequent service in order to develop convenience and utility. With modern airplanes a short operation can be considered to be anything of the order of 500 miles. Air journeys are gradually getting longer. Fig. 4 shows that the average passenger now flies close to 500 miles on the average airline. If he flies on T.W.A. he averages higher than that for this line is, as the name implies, a transcontinental operation primarily. On American Air Lines, whose operations are largely concentrated in the East with short flights, the average is lower. United Air Lines, being more balanced between main line and feeders, strikes close to the average. Actually the traveler really flies further than is shown for, when he changes from one line to another, he then appears twice in the statistics.

In order to compete in the field of moderate length journeys, that is journeys that can be flown conveniently in normal day and evening hours, the use of less luxurious, lower cost transportation, that can be sold at a reduced fare, will allow the airline to compete to better advantage.

For the longer trips the attempts to develop more luxurious, comfortable accommodations on the part of the airline operators is correct for they can thereby develop the advantage of having two of the primary factors in their favor—comfort and speed—and business will accrue accordingly.

Icing of Pitot Static Tubes

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Presented at the Instruments Session, Sixth Annual Meeting, I. Ae. S.
January 24, 1938

EARLY requirements for heated pitot static tubes for the operation of air-speed indicators were subordinate to the greater problem of ice accumulation on the lifting surfaces of the airplane. The purpose of pitot tube heating was merely that of delaying ice formation thereon so as to insure operation of the air-speed indicator as long as the airplane could fly.

But when devices which removed ice continuously from wing and tail surfaces permitted sustained flight under adverse conditions, it became necessary that the air-speed indicator should operate at all times.

The first electrically heated pitot static tubes commercially available had a heating element consuming approximately 50 watts, based on the rather limited information then available. In 1937, some serious tests were initiated by the Army Air Corps and by United Air Lines, using the facilities of the B. F. Goodrich Company in whose refrigerated wind tunnel (Fig. 1) experiments can be carried out under severe ice-forming conditions.

Wind Tunnel Test Procedure

Refrigeration of the tunnel was begun twenty-four hours prior to start of the test. During refrigeration the propeller was rotated slowly, the slow passage of the tunnel air through the brine coils accelerating the rate of cooling. The pitot tube to be tested was placed in the tunnel approximately one hour before the first run. The tube was therefore assumed to be at tunnel temperature at the start of each series of tests.

When making a test the tunnel was turned on, the time observed, and then as quickly as possible the water spray was inserted and turned on. The sprayer consisted of a small tube carrying water and a parallel tube carrying compressed air. There were three short orifices in the water tube and three corresponding orifices in the air tube. The air nozzles were longer and bent over at right angles to the water jets, breaking them into fine spray. The sprayer was placed horizontally in the tunnel in front of the throat, approximately four feet from the pitot tube.

Ice formed immediately on the nose and sides of the tube. When the ice cap at the nose was approximately $^5/_8$ in. thick the current was turned on and the time recorded.

A record was made of the behavior of the air-speed indicator both when rendered inoperative by the ice formation, and when restored by application of heat. The final readings of voltage and current and the time required for them to become stable were recorded. The elapsed time before the ice cap left the nose of the pitot was also recorded.

Generally the heat was left on for a short time after a test so that the accumulated ice could be removed more easily. After the ice was removed the current was turned off and the tube and tunnel cooled to approximately 0°F. before the next test was begun.

If a picture was required at the completion of a test the heat was turned off at the same time the water spray was removed. The tunnel was then left on for a short time, until the residual heat in the tube had been dissipated. The tunnel was then turned off and a picture taken.

The only exception to this procedure was made in the first test, when the pitot-tube current was turned on before starting the water spray.

Test Results

In the first test, 50 watts appeared to be barely sufficient to maintain the pitot and static orifices open if no ice was permitted to accumulate thereon before turning on the current (Fig. 2). But if the current was turned on after ice had already formed, it would continue to accumulate in certain places at a rapid rate, in spite of the heating (Fig. 3).

Furthermore, the parts of the pitot tube in back of the static orifices would accumulate ice under all conditions, and continued accumulation would undoubtedly lead to severe disturbance of the air stream with consequent errors in the static pressure.

A critical survey of the problem suggests that the requirement is not that of heating the air flowing past the tube, nor that of raising the temperature of the water droplets in the air above the freezing point, but rather that of melting the inner face of an incipient coating of ice, so as to let the air stream blow it off.

If this is true, the heating requirements will not vary with the speed of the aircraft in such a way as to maintain a given relation between air-mass flow and current input.[1] The only difference that a change in air speed would make should be in the thickness of the fragments of ice removed by the combined action of the heat and the air stream, the thickness bearing a proportional relation to the air speed for given atmos-

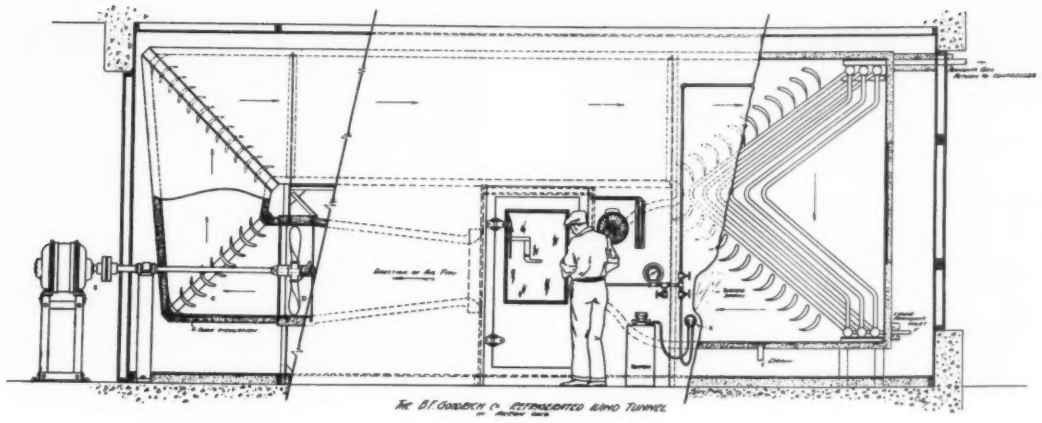

FIG. 1.

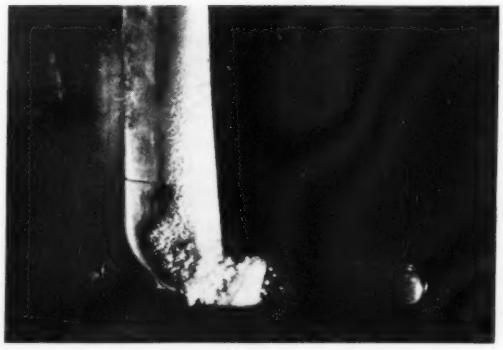

FIG. 2. 50 watts dissipated by tube. Current on before turning on water sprays.

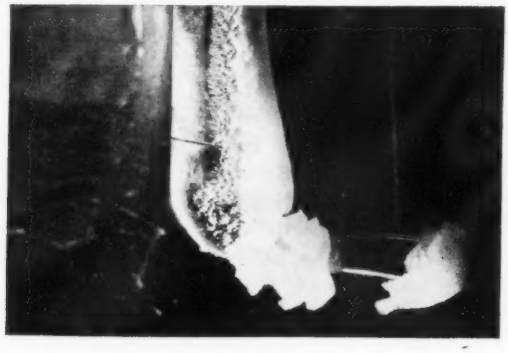

FIG. 3. 50 watts dissipated by tube. Tube was permitted to ice before turning on current.

FIG. 4. 115 watts dissipated by tube. Single heater at nose of tube.

pheric conditions.[2] With this hypothesis it is assumed that the surface of the tube be uniformly heated.

At the nose, the shape of the ice cap is such as to prevent easy shedding, and the heated tube must be relied upon to melt a hole through the ice. The resulting ring of ice will then slide backwards, propelled by the air stream, with sufficient force to break and fall off.

As a first approach to the problem, some new experiments were run with increased current input. Fig. 4 shows the results obtained with 115 watts in a single heating element about 2 in. long, located as far as possible forward of the tube jacket. This heating element was the same in dimensions and location in all of the tests, the only variable being the current consumption.

The vertical streamlined member, to which the airspeed tube is attached, will accumulate ice. An inflatable rubber boot has been successfully employed to remove the ice from this member, and recently, the Goodrich Company has undertaken to experiment with a special boot which will envelop the trailing end of a specially built tube. If the experiment is successful, this combination of pitot-tube support and de-icer may meet all of the requirements.

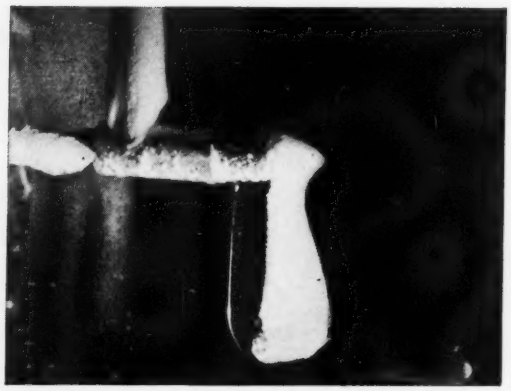

FIG. 5. 114 watts dissipated by tube. Single heater at nose of tube.

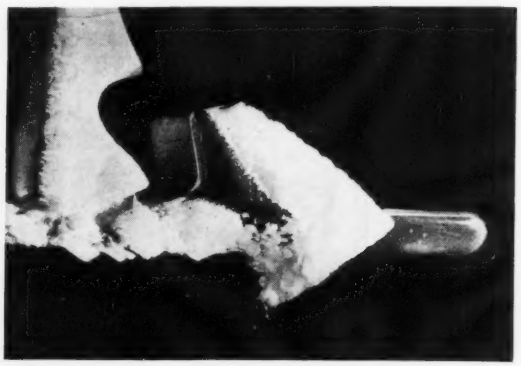

FIG. 6. 133.2 watts dissipated by tube. Single heater at nose of tube.

The tube illustrated in Fig. 5 is employed at the end of a tubular boom attached to the leading edge of monoplane wings. The construction of this tube with a vertical portion had been used previously in an attempt to prevent water from getting into the connecting tubes, although its value as preventive means for the entrance of water appeared doubtful. Moreover, unless the heat source were made sufficiently powerful so as to destroy the ice completely, the mere creation of a water film between the ice and its support would not be sufficient, since the shape of the vertical portion would cause the ice coat to cling to it.

However, some provision must be made to take care of water, because, unquestionably, as the heated pitot tube melts its way into a thick cap of ice, a plug thereof will enter the pitot opening and melt.[3]

If this happens rather suddenly, the small drain hole provided for the disposal of water might not be sufficient to discharge a large amount of water in a very short time, and it might happen that through acceleration, change in attitude, *etc.*, the water, instead of being eliminated, would find its way into the unheated connecting tubes where it would freeze.

Preferably, the vertical riser must be eliminated, or modified in order to facilitate the pushing off of the ice by the air stream. An adequate trap must be provided so that if a relatively large quantity of water should enter the pitot tube, it could be temporarily trapped and subsequently eliminated by a small drain hole.

The tube shown in Figs. 6, 7, 8, and 9 was the result of such considerations. The shark fin shaped riser serves as a water trap for both the static and pitot lines, while the sloping leading edge facilitates the discharge of ice gliding on the water film.

Fig. 6 shows the first of these tubes after a test in the refrigerated tunnel. As in the previous tubes, a single heater at the nose was employed, but the power was increased to 130 watts.

The results were disappointing considering the relatively large increase in wattage over that used in previous experiments, and it seemed logical to conclude that an increase in wattage alone would not furnish the answer. This opinion is strengthened further by the results obtained in the succeeding tests.

The tube in Figs. 7 and 8 was equipped with two heating elements, one of which was located near the nose, as in all of the other tubes tested, and the other, in tandem arrangement, just back of the first. Several tests were run with not less than 130 watts current input. As in previous tests the ice was permitted to build up to an estimated $^5/_8$ in. before the current was turned on.

With 130 watts, after melting through the cap of ice, without, however, being completely free over the whole length (some large lumps of ice were left on the fin and on the trailing end of the tube), ice began to accumulate again on the nose, and, in a very short time, the pressure orifice was again entirely closed.

With 180 watts, the same tube did not show a tendency to gather ice again at the nose, but it was not able to rid itself of the large accumulations on the trailing regions. The ice on the fin started to move upward, but almost immediately refroze.

Fig. 2 shows that if the current is turned on, even with a limited wattage, before freezing begins, ice does not form anywhere on the airspeed tube except on those parts most remote from the heat source. Water drops are seen to flow along the tube and gather at the unheated end, where they freeze.

But in the test of Fig. 7, where ice was first permitted to form and then removed by the application of heat, resulting in the forward two-thirds of the tube length being completely free of ice, new ice growths began to form on the heated tube in spite of the fact that heat was being supplied at a greater rate than in the test of Fig. 2.

Since 50 watts was enough to prevent ice formation, the failure of 130 watts to do likewise could only be explained by assuming that the presence of ice growths on the tube substantially alters the flow of air around the tube. With relatively smooth flow (Fig. 2), when

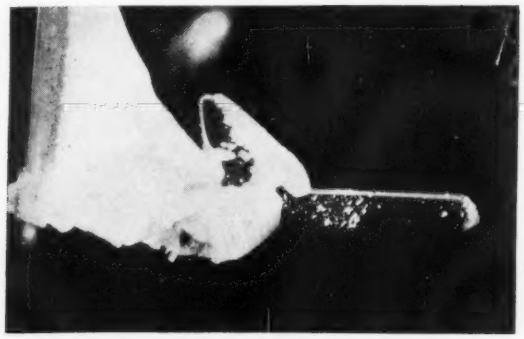

FIG. 7. 131 watts dissipated by tube. Two heaters in tandem.

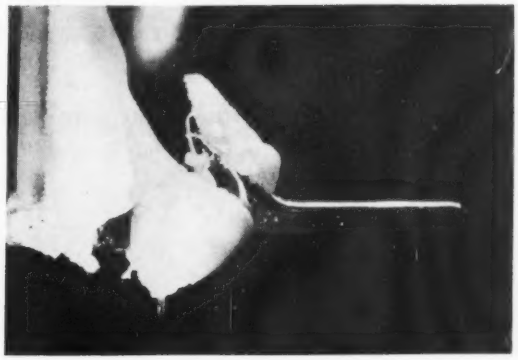

FIG. 8. 178 watts dissipated by tube. Two heaters in tandem.

the heat loss by convection is negligible, the temperature of the tube remains high enough to melt the ice as fast as it is formed. The highly turbulent flow due to the presence of ice, however (Fig. 7), increases the rate of heat transfer from the tube to the air to a point where the tube is cooled below the melting point of ice.

The extent of this increase in heat transfer can be better estimated if it is recalled that the quantity of heat lost by the tube is proportional to the loss of momentum by the air mass flowing past it,[4] and there is no doubt that the accumulation of ice has an unfavorable effect on the flow about the tube.

The existence of an unsteady state of flow is also indicated by the spotty nature of the ice formation and by irregularities in the indication of the airspeed indicator connected to the tube, the instrument indicating, in some cases, 17 m.p.h. more than the known tunnel speed.

It is evident then that, in order to insure continuous operation of the air-speed tube, no ice must be left thereon. With the exception of the nose, where the ice cap must be melted through in order to remove it, it will be sufficient if, at all other points of the tube, the temperature of its surface is maintained sufficiently high to melt a water film, and permit the ice to be blown off. But this heat must be due to internal sources, properly distributed, and the thermal conductivity of the tube jacket cannot always be relied upon to transfer the heat from the heating elements to all regions of the tube.

Fig. 9 shows in a striking manner the far reaching effect due to an improved distribution of the internal source of heat. In this tube, the second heater, instead of being just back of the first, was placed further aft and located more centrally with relation to the exposed areas of the trailing half of the tube. With an input of 130 watts, the tube was cleared of ice completely, only the leading edge of the fin showing thereafter a tendency to gather ice again. This seems logical in view of the fact that the upper half of the fin, where the ice started to form, was the most remote from the heater, the heat being transmitted to that point through the outer shell of the fin.

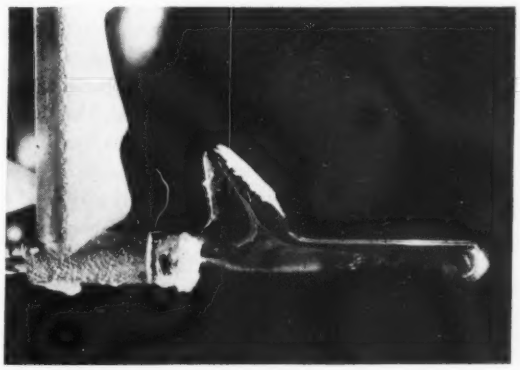

FIG. 9. 132 watts dissipated by tube. Two heaters rearranged for better heat distribution.

With a slightly higher wattage, no tendency for ice to gather was displayed by the tube. After the removal of the first accumulation it remained completely clear throughout the test. The better performance must be ascribed entirely to better distribution of the heat source within the tube, since no change was made in any of the test conditions.

The results of the tests conducted so far are not complete, but they indicate beyond reasonable doubt that the approach to solution of the problem was correct.

New tubes, designed and made since the last test, have shown greatly improved efficiency and will undoubtedly perform better, with the desirable result of restricting the wattage to a reasonably sufficient minimum.

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[3] Carroll, T., and McAvoy, W., *The Formation of Ice upon Airplanes in Flight*, N.A.C.A. Technical Note No. 313, 1929. This reference describes ice formations inside Pitot Tubes.

[4] Stanton, T., Phil. Trans. Roy. Soc., A190, 67, London, 1897. See also *Note on the Relation between Skin Friction and Surface Cooling*, N.A.C.A. Technical Report, 1912–13.

Some Aspects of Airfoil Skin Friction

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January 26, 1938

Introduction

THE aerodynamic phases of airplane design have, along with other subdivisions, made great advances in the past decade. The large airplane in particular has changed from an externally braced structure to one of extremely clean appearance. As a result of these developments that portion of the resistance which depends exactly on the square of the velocity has gradually decreased in importance. At the same time, the portion of airplane drag due to skin friction has become an increasingly large part of the total. This latter item is now known to depend on the Reynolds Number of the flow, on the roughness of the surface of the exposed body, and on the initial turbulence of the relative air stream. Unfortunately, however, quantitative data covering all these effects are not available for all shapes of bodies.

A further result of the present trend toward aerodynamic cleanness has been to increase in importance the profile-drag of the airplane wing. This paper is concerned with some problems relating to the skin friction of airfoils, and particularly with methods for determining full-scale drag values from wind-tunnel tests at rather low Reynolds Numbers.

General Considerations of Airfoil Drag

In general, the drag of any submerged body, exclusive of the induced drag due to lift, may be considered as made up of two parts, that is

$$D = D_{skin\ friction} + D_{eddy\ making} \tag{1}$$

The first item, the skin friction drag, is present on all surfaces in contact with the fluid. It is dependent mainly on the Reynolds Number of the flow and on the type of flow present in the boundary layer adjacent to the body surface. "Eddy making" drag is usually of appreciable importance only for bodies of bluff form and for airfoils at high angles of attack. Unless the body is to operate at or near the Reynolds Number associated with the critical condition entailing a change from a laminar to a turbulent boundary layer, the eddy making drag may be assumed to be independent of Reynolds Number. For airplanes at the high speeds of flight now employed for cruising, the angle of attack of the wing is so low that practically no eddy making drag is present.

Skin Friction on Flat Plates

A detailed study of airfoil skin friction drag is best begun by a consideration of the simple case of a flat plate at zero angle of attack. In this case there is no eddy making drag while the skin friction depends on the nature of the boundary layer flow, that is, whether it is laminar or turbulent. For a two-sided plate with a laminar boundary layer, Blasius[1] has shown that the skin friction drag coefficient is

$$C_f = 2.654/\sqrt{N_R} \tag{2}$$

For a turbulent boundary layer, the first results were obtained by von Kármán[2] in the form

$$C_f = 0.148/N_R^{1/5} \tag{3}$$

on the assumption that the transverse velocity distribution in the boundary layer varies as the $^1/_7$ power of the distance from the plate.

More recent work by von Kármán and its application by Schoenherr and Schlichting have led to a somewhat more satisfactory relation in the form

$$C_f = 0.910/(\log_{10} N_R)^{2.58} \tag{4}$$

which is based on a logarithmic relation for the velocity distribution across the boundary layer.

Beginning with a plate on which the boundary layer is laminar, it is found that as the Reynolds Number is increased, a critical value N_c is reached at which turbulence sets in at the trailing edge and then progresses forward for further increases in N_R. Following Prandtl's work, Eqs. (2) and (4) may be combined to give for this transition range the value

$$C_f = [0.910/(\log_{10} N_R)^{2.58}] - (1/N_R)[0.910\ N_c/(\log_{10} N_c)^{2.58} - 2.654\ N_c^{1/2}] \tag{5}$$

The values of C_f plotted against N_R, obtained from Eqs. (2), (4), and (5), are shown on the logarithmic chart of Fig. 1, a value of N_c of 500,000 having been used in Eq. (5).

In the past it has frequently been the practice to assume that C_f varies with Reynolds Number according to an exponential relation of the form illustrated by Eq. (3). It is obvious from Fig. 1 that this assumption would be only a rough approximation and of reasonable validity only for the extreme right-hand portion of the curve. The actual slope of the curve represented by

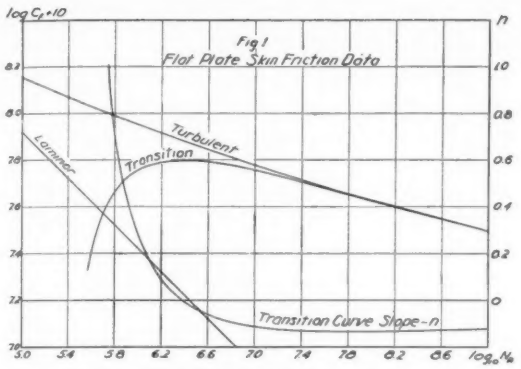

FIG. 1. Flat-plate skin friction data.

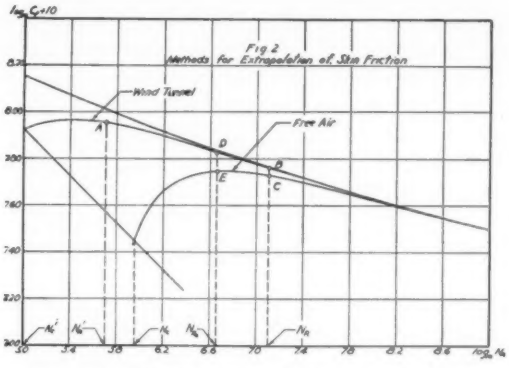

FIG. 2. Methods for extrapolation of skin friction.

Eq. (5), when plotted on logarithmic scales, may be found by differentiating $\log_{10} C_f$ with respect to $\log_{10} N_R$. The result is

$$n = d(\log_{10} C_f)/d(\log_{10} N_R)$$

$$= \frac{-0.4343}{C_f}\left[\frac{2.58}{\log_{10} N_R} C_{f_T} - 2.3026\left(\frac{3240}{N_R}\right)\right] \qquad (6)$$

where C_f is given by Eq. (5) and C_{f_T} is its first term $0.910/(\log_{10} N_R)^{2.58}$, corresponding to a completely turbulent boundary layer. Values of n are plotted against $\log_{10} N_R$ in Fig. 1. This curve shows very clearly the conditions under which it is possible to approximate the relation between C_f and N_R by an equation of the form

$$C_f = K/N_R^{\,n} \qquad (7)$$

For values of N_R between 10^7 and 10^9, a value of n of about 0.13 would be satisfactory. In general, however, it is most advisable to follow Eq. (5) rather than Eq. (7), particularly when the transition range is to be considered.

Effects of Turbulence and Surface Roughness

Initial turbulence of the fluid stream moving relative to the plate and roughness of the plate surface both produce rather similar effects on the resistance. An increase in either of these factors tends to hasten the transition from laminar to turbulent flow in the boundary layer and to decrease the value of the second term in Eq. (5). For the present, only the effect of varying turbulence will be considered in detail.

At this time information as to the exact relationship between turbulence and critical Reynolds Number is not available for the flat plate, although Dryden[3] indicates that N_c lies between 10^5 and 1.1×10^6. This situation further complicates the problem of extrapolation to the high Reynolds Numbers of full-scale conditions. In general, the atmosphere is extremely low in turbulence while wind tunnels, in which most experimental work is done, are considerably higher in turbulence due to the effect of walls, guide vanes, honeycombs, *etc.* A typical situation might be that illustrated in Fig. 2 in which N_c represents the critical Reynolds Number in free air and N_c' its value in the more turbulent wind tunnel. In order to extrapolate from a test Reynolds Number N_R', in the tunnel to a value N_R in free air, it is necessary to pass along the upper transition curve from A to B and then from B to C on the free-air curve. The difference in the C_f values at A and B might be termed the scale correction and attention should be called to the fact that this may be either positive or negative depending on the relative values of N_R' and N_R. The drop in C_f required to pass from point B to C might be called the turbulence correction.

An alternative method for making the combined scale and turbulence corrections has been proposed by the National Advisory Committee for Aeronautics.[4] In this system, the test Reynolds Number is multiplied by a turbulence factor N_c/N_c' to produce an effective Reynolds Number N_{R_c}. The corrections are then made by passing along the path $ADEC$. Both methods produce identical results but simply follow different paths in getting from A to C.

The weak point in these extrapolation methods is the present lack of accurate data relating turbulence and critical Reynolds Number. The N.A.C.A. method is now based on turbulence factors estimated from sphere tests, but the question immediately arises as to how closely these results apply to airfoils. It would seem that turbulence factors based on flat-plate tests would be more suitable for the usual airfoil shapes of moderate camber and thickness and low angle of attack. For tests made at a high Reynolds Number the turbulence correction is not of great importance. However, it is extremely important for tests made in low scale atmospheric wind tunnels. In such cases it is advisable for measurements of airfoil drag to be made at values of N_R greater than N_c' so as to avoid the laminar range. However, more accurate information concerning the transition will greatly increase the effectiveness and reliability of tests made in wind tunnels of this class.

Skin Friction Drag of Actual Airfoils

The skin frictional resistance of an actual airfoil might be thought of as equivalent to a flat plate of the same

exposed surface. Even though account is taken of the changes in velocity over the profile surface, this equivalent flat-plate method does not account for all of the drag. Computations have been made for a Joukowski profile of symmetric section having a thickness ratio of 26 percent using the theoretical velocity distribution as a basis for computing the shear stress and total skin friction. Using a parabolic velocity distribution across the boundary layer for laminar flow, the result was

$$C_f = 4.00/\sqrt{N_R}$$

or an increase of 51 percent over that for the flat plate. For simplicity, the $^1/_7$ power law was used for turbulent flow, the result being

$$C_f = 0.196/N_R^{1/5}$$

or an increase of 32 percent over the flat-plate coefficient given by Eq. (3). Experimental tests[4] indicate much larger increases for the case of a turbulent boundary layer, while the results in the laminar range are too irregular to enable any conclusions to be drawn from them. At a Reynolds Number of 10^7, these tests show that a symmetric airfoil of 26 percent thickness ratio would have an estimated drag coefficient of 0.0115 or about 100 percent greater than that for the flat plate. Although some of the difference between this 100 percent increase and the value of 32 percent obtained above may be due to the development of some eddy making drag on the thick profile considered here, it appears conclusive from preliminary calculations on thinner profiles that the skin friction method outlined above will not account for all of the drag.

These differences between the airfoil and the flat plate are due mainly to the fact that there is a pressure gradient over the surface of the former. This produces a distortion of the boundary layer velocity profiles which is reflected in a change in shear stress and skin friction drag. Thus it may be shown that if the velocity distribution across the boundary layer is of the form

$$u = V_0(y/\delta)^m$$

then the relation between C_f and Reynolds Number is

$$C_f = K/N_R^n$$

where $n = 2m/(3m + 1)$. Thus, when $m = {}^1/_7$, $n = {}^1/_5$, as in Eq. (3), while the values for a few other cases

TABLE 1

Values of m and n in Turbulent Skin Friction Formulas

m	1/4	1/5	1/6	1/7	1/8	1/9	1/10
n	2/7	2/8	2/9	2/10	2/11	2/12	2/13

are given in Table 1. These figures show that for the fuller velocity profiles corresponding to the smaller values of m, the drag coefficient decreases less rapidly with Reynolds Number.

The above calculations merely serve to indicate that the distortion of the boundary layer velocity distribution on an airfoil produced by the pressure gradient may be manifested in a change in the slope of the $C_f - N_R$ curve. Thus the total skin friction drag of the airfoil might be considered as that of an equivalent flat plate plus that due to boundary layer distortion, although at present we have little information as to the way in which this distortion component varies with Reynolds Number. However, the most complete test data[4] indicate that the curves for airfoils plotted logarithmically very nearly parallel those for the flat plate, particularly at the higher Reynolds Numbers. On this basis it would appear reasonable to extrapolate to full-scale Reynolds Numbers for the airfoil in the same way as was done for the flat plate. In fact, we might conclude that C_D for an airfoil is related to its model test value C_D' by the equation

$$C_D = C_D' C_f/C_f'$$

where C_f' and C_f are the flat plate coefficients at model and full-scale Reynolds Numbers.

The only difficulty remaining in making this extrapolation for the airfoil lies in the fact that the pressure gradient has a very pronounced influence on the transition and the critical Reynolds Number. Here is found the most serious lack of exact experimental information without which no complete solution to the present problem can be obtained. Whether the use of critical Reynolds Numbers for the flat plate is justified can be determined satisfactorily only by more exhaustive research on the transition phenomena.

CONCLUSION

The conclusions to be drawn from this very brief study of airfoil skin friction are that for the higher Reynolds Numbers, the relation between drag coefficient and Reynolds Number is of the same form as for the flat plate. The behavior of the transition under varying turbulence and pressure gradients are only qualitatively known at present. Experimental study of these problems is acutely needed and should lead to greater accuracy in the extrapolation of model test results to full scale conditions. The effectiveness of the low-scale atmospheric wind tunnel will be greatly increased by such additions to aerodynamic knowledge.

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Selection of the Optimum Aspect Ratio for a Cantilever Sailplane

WALTER CASTLES, JR., *Georgia School of Technology*

Presented at the Aerodynamics Session, Sixth Annual Meeting, I. Ae. S.
January 26, 1938

SUMMARY

This paper presents an analytical method, based on several simplifying assumptions, of selecting the optimum sailplane aspect ratio for flattest gliding angle or lowest sinking speed for any given span, wing section, and drag of fuselage and tail. Curves are given for each case to illustrate the variation of the optimum aspect ratio with the sailplane parameters.

THE sailplane wing span which gives the ultimate in performance is almost always greater than is practical from the standpoint of maneuverability, ease of handling on the ground, and cost. Therefore, the span is usually determined by what the designer considers a good compromise. Also, the minimum fuselage drag is governed to a large extent by the cross-section necessary to enclose the pilot.

A considerable part of the aerodynamic design, which this paper is intended to simplify, then consists of determining what aspect ratio will give the best performance in conjunction with the selected span and wing section, and the estimated fuselage and tail drag.

The assumptions made in deriving the formulas are:

(1) The induced drag, C_{D_i}, can be written as $C_{D_i} = C_L^2/(\pi b^2/S)$, where b is the geometric span. This will be very nearly true since sailplane wings are usually a fairly close approximation to an ellipse in planform.

(2) The induced drag of the tail is zero. That is, the sailplane is balanced for zero tail load at the flight condition for minimum gliding angle or sinking speed as the case may be.

(3) The weights of the components of the sailplane can be represented with sufficient accuracy by Lachmann's weight formula.[1]

ASPECT RATIO FOR FLATTEST GLIDING ANGLE

The profile-drag coefficient, C_{D_0}, of a wing section can be written with a sufficient degree of precision over the pertinent range of lift coefficients, as $C_{D_0} = C_{D_{00}} + a(C_L - C_{L_0})^2$, where $C_{D_{00}}$ is the minimum profile-drag coefficient, C_{L_0} is the lift coefficient for minimum profile-drag, and a is a constant for any wing section and is determined from the profile-drag polar (say at $C_L = 1.1$ or 1.2).

Let A = fuselage and tail drag area in ft.^{2}, where A is a fictitious area whose absolute drag coefficient is unity, b = span of wing in ft., S = wing area in ft.^{2}, and Λ = aspect ratio.

Then the parasite-drag coefficient, $C_{D_p} = A/S = B\Lambda$, where $B = A/b^2$, and the total drag coefficient, C_D, is

$$C_D = C_{D_{00}} + a(C_L - C_{L_0})^2 + B\Lambda + C_L^2/\pi\Lambda$$

or

$$F(C_L,\Lambda) = C_D/C_L = [C_{D_{00}} + a(C_L - C_{L_0})^2 + B\Lambda + C_L^2/\pi\Lambda]/C_L \quad (1)$$

By minimizing this expression, the aspect ratio and lift coefficient for minimum D/L are found to be

$$\Lambda = [(C_{D_{00}} + aC_{L_0}^2)/\pi aB]^{1/2} \quad (2)$$

and

$$C_L = [(C_{D_{00}} + aC_{L_0}^2)/a]^{1/2} \quad (3)$$

From Eqs. (1), (2), and (3), the minimum D/L for the given span, wing section, and fuselage and tail drag area is found to be

$$(D/L)_{min.} = 2(aC_{D_{00}} + a^2C_{L_0}^2)^{1/2} - 2aC_{L_0} + 2(B/\pi)^{1/2} \quad (4)$$

It is interesting to note that the lift coefficient for minimum D/L of a sailplane designed for flattest gliding angle depends only on the wing section. It is the same lift coefficient as that at which the minimum D/L for the profile-drag occurs.

ASPECT RATIO FOR LOWEST SINKING SPEED

Lachmann[1] gives the following formula for the weight of a cantilever single-spar wooden sailplane with a torque tube leading edge and a monocoque fuselage.

The total weight, $W = Xb + yS + Zb^3 + U$, where $X = 2.2$ (lbs. per ft. span) for fuselage, $y = 0.78$ (lbs. per ft.^{3}) for ribs, covering, etc., $Z = 0.00041$ (lbs. per ft.^{2}) for span, and U = disposable load in lbs. The constants in the above formula may be different for some other form of construction.

The sinking speed, V_s, in ft. per sec. is $V_s = VC_D/C_L$ where V is the forward speed in ft. per sec.

But $$V = [2W/\rho SC_L]^{1/2} = C_1(\Lambda + h)^{1/2}/C_L^{1/2}$$

where $C_1 = [2(Xb + Zb^3 + U)/\rho b^2]^{1/2}$ and is constant for given b and ρ, and h = (coefficient of variable wt.)(b^2)/(constant wt.) or $h = yb^2/(Xb + Zb^3 + U)$

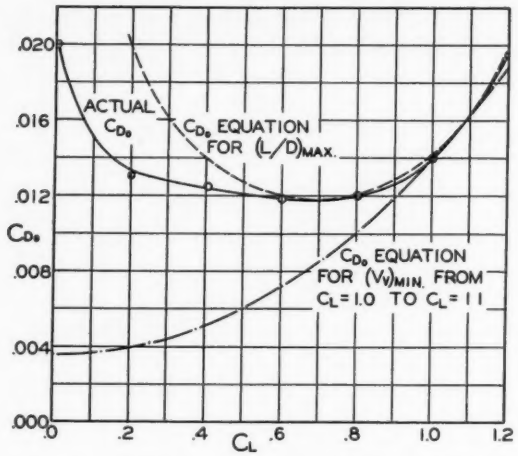

FIG. 1. Comparison of the profile-drag equations for $L/D_{max.}$ and $V_{v_{min.}}$ with the profile-drag polar for N.A.C.A. 6412. Effective Reynolds Number = 645,000.

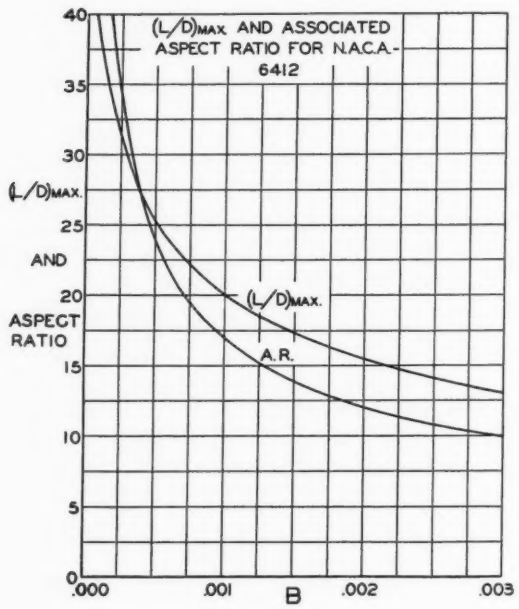

FIG. 2.

In order to avoid final equations which were too complicated for ready solution, it was found necessary in this case to use an equation for C_{D_0} that could be fitted to only one part of the profile-drag polar at a time.

Let $C_{D_0} = e + gC_L^2$, where e and g are considered constants for any given wing section, but only for a small range of lift coefficients. That is, if e and g are determined from the profile-drag polar of an airfoil at $C_L = 1.2$ and $C_L = 1.3$, $e + gC_L^2$ will give the correct value of C_{D_0} between these values of C_L, but not necessarily outside them.

Then the total drag coefficient, C_D, can be written

$$C_D = e + gC_L^2 + B\Lambda + C_L^2/\pi\Lambda$$

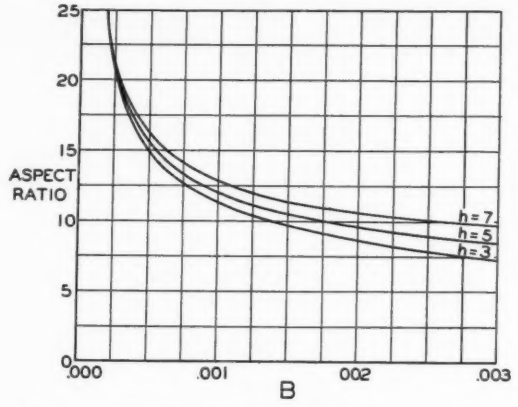

FIG. 3. Aspect ratio for minimum sinking speed. N.A.C.A. 6412 airfoil.

and the sinking speed will be

$$V_s = C_1(e + gC_L^2 + B\Lambda + C_L^2/\pi\Lambda)(\Lambda + h)^{1/2}/C_L^{3/2} \quad (5)$$

Minimizing this expression gives the aspect ratio for minimum sinking speed in the form of a cubic

$$\Lambda^3 + \left(\frac{2e}{3B} + \frac{h}{3}\right)\Lambda^2 - \left(\frac{2h}{3\pi g} + \frac{e}{\pi Bg}\right)\Lambda - \frac{eh}{\pi Bg} = 0 \quad (6)$$

which can be solved for the aspect ratio, Λ, by any of several methods among the easiest of which is Newton's method of successive approximations.[2]

The lift coefficient for minimum sinking speed is

$$C_L = [3\pi\Lambda(B\Lambda + e)/(\pi g\Lambda + 1)]^{1/2} \quad (7)$$

If the value of C_L given by Eq. (7) does not lie between those used to determine e and g, it will be necessary to repeat the process with new values of e and g.

Once the correct values of the aspect ratio and lift coefficient are obtained, the minimum sinking speed for that span, wing section, and fuselage and tail-drag area can be found from Eq. (5).

DISCUSSION

Fig. 1 shows a comparison of the profile-drag equations for the case of flattest gliding angle and lowest sinking speed with the actual profile-drag polar for the N.A.C.A. 6412.

Fig. 2 gives the $(L/D)_{max.}$ and associated aspect ratio for the N.A.C.A. 6412 wing section over a wide range of the parasite drag parameter. It shows that the variation of the optimum aspect ratio is the most critical for low values of the drag parameter.

For the same airfoil and range of the drag parameter Fig. 3 presents the aspect ratio for minimum sinking speed for an average and two extreme values of the weight parameter. For the more efficient sailplane the weight parameter appears to have little effect upon the aspect ratio.

The N.A.C.A. 6412 wing section was used as a basis

for the curves because it is one of the few new sections, suitable for sailplanes, on which profile-drag data at appropriate Reynolds Numbers have been published.

Since sailplanes operate at Reynolds Numbers in the vicinity of a million where critical changes take place in the profile-drag, particularly at the higher lift coefficients, most of the available airfoil data are not very applicable to sailplane performance analysis.

There is a very real need for published airfoil section data at sailplane Reynolds Numbers on new profiles, such as the N.A.C.A. 63015, that appear from V.D.T. data to be superior to the sections used at present.

The external airfoil flap[3] appears to present a means of substantially improving sailplane performance as it has a very low profile-drag at the higher lift coefficients. Also, it offers possibilities of more nearly meeting the different optimum aspect ratio requirements for best gliding angle and minimum sinking speed with a fixed aspect ratio by merely changing the flap setting.

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Book Reviews

Handbook of Aeronautics, Vol. I, published under the authority of the Royal Aeronautical Society, Sir Isaac Pitman & Sons, Ltd., London, 1938, 624 pages, $10.00.

This well known handbook first appeared in 1931, with a revised edition in 1934. Now there is a third and enlarged edition. The work is in three volumes, Volume II being devoted to Engines and Volume III to Design Data and Formulae including Propellers.

Volume I, now at hand, is a much condensed but highly authoritative statement of basic data, together with a wealth of miscellaneous information on standard materials and equipment which may or may not be useful to an American reader. It should be of interest, however, if only for comparison with our practice.

The opening chapter on Aerodynamics by E. F. Relf of the N.P.L. adopts the C coefficients, in line with the United States and the Continent of Europe, thus breaking with the British tradition of K coefficients which were numerically half as great. The Aerodynamics chapter gives data for typical wing profiles at high Reynolds Number based on N.P.L. compressed wind-tunnel tests. The effect of camber, thickness, roughness, slots, split flaps, tabs, aspect ratio, etc., are set forth in tables or curves taken from R. & M. or N.A.C.A. Reports. The material given is necessarily brief but it is noted that plain and slotted flaps and variable area flaps are not mentioned.

The treatment of stability and control gives practical rules for a designer which should be helpful.

Captain Liptrot goes through a complete performance calculation in his chapter, giving for ready reference a good deal of drag data and the necessary charts for computations. Performance is more fully discussed than one might expect in a handbook. It is in fact a treatise on the subject, including the take-off problem, cruising speed and range, and rotary wing aircraft.

The chapter on Construction by M. Langley is essentially a collection of handbook data on standard parts, and typical construction practice for wing spars, ribs, shell, fittings, fuselage elements, controls, mounts, etc. This data evidently represents current British practice and is worth review by American designers to note the quality of material specified for such parts.

Colonel Outram and Mr. F. S. Clare contribute a chapter on Materials, which is a digest of Air Ministry specifications. American designers will find this an authoritative statement, most convenient and suggestive for comparison with our own practice.

Mr. C. J. Stewart's chapter on Instruments is largely descriptive of the flight instruments now in use, including oxygen apparatus, navigating equipment, bonding and radio installation. This material is not detailed enough to be very useful to a designer and of little value to a student of instrument design. However, a bibliography refers the reader to the technical literature on each kind of apparatus.

Mr. Kemp's article on Air Survey and Photography and Captain Entwistle's chapter on Meteorology are very brief collections of useful tables of data and conversion and reduction formulae frequently used, with some remarks and suggestions. Perhaps this is all that an airplane designer wants to know about such special subjects.

The final chapter by Mr. Needham discusses the Design and Construction of Gliders and Sailplanes which, in view of the scarcity of published data, should be useful to an amateur. The treatment, in 37 pages, is necessarily very brief.

On the whole, the Handbook is interesting, and different parts of it will be useful to different people. Aeronautical engineering practice is perhaps not yet sufficiently standardized to justify a handbook of the character of those available in the older fields of engineering. Perhaps the Royal Aeronautical Society will eventually develop such a publication. The working library of the modern airplane designer is now a collection of books, monographs, and dog-eared periodicals in several languages, from which only a very experienced man may be trusted to extract reliable information.

J. C. HUNSAKER

Aviation as a Career, and **Aeronautics (non-flying) as a Career;** Institute for Research, Chicago; 35 and 28 pages, respectively, 1937.

The first of these monographs takes up rather completely the pros and cons of flying as a career. Statistics of the Aviation industry for 1935 are followed by sections devoted to general qualifications, advantages and disadvantages, training required for the various classes of pilots, duties, opportunities, salaries, and the average duration of a pilot's career.

Relatively high salaries, short hours, and the romance connected with flying must be weighed against the high qualifications necessary, hazards, short average duration of a pilot's career, high physical standards which must be maintained, relatively limited number of openings, and the high cost of training, particularly for transport pilots. Those fortunate enough to attend the Army or Navy flying schools are spared most of the expense of training.

It is pointed out that a transport pilot's career as such is generally over by the time he reaches the age of 45. However, there are some opportunities for them to change over to executive or scientific positions.

(*continued on page 412*)

The Weather Bureau's Radio Meteorograph Program

L. T. SAMUELS, *U. S. Weather Bureau*

Presented at the Meteorology Session, Sixth Annual Meeting I. Ae. S.
January 25, 1938

DURING the past two years, remarkable progress has been made in this country in the development or radio meteorographs, at least five different types having been devised. In January, 1937 when it was necessary for the Weather Bureau to decide on a program for the fiscal year 1938 no one type had been sufficiently developed for regular use in scheduled observations. It was therefore deemed advisable to continue investigating all five types in order to explore thoroughly the best features of each. These types were designed by the following:

(1) Messrs. H. Diamond, W. S. Hinman, Jr., and F. W. Dunmore of the National Bureau of Standards in cooperation with the Navy Department.

(2) L. F. Curtiss and A. V. Astin of the National Bureau of Standards in cooperation with the Weather Bureau.

(3) O. C. Maier and L. E. Wood of the California Institute of Technology.

(4) K. O. Lange and A. E. Bent of Blue Hill Observatory.

(5) The Weather Bureau in cooperation with Julien P. Friez and Sons, Baltimore, Md.

With regard to the first type mentioned, development was continued by Diamond and his collaborators who are giving a progress report of their work which will appear in an early issue of this Journal.

In connection with the radio meteorograph designed by Curtiss and Astin, a sum of money was again transferred this fiscal year by the Weather Bureau to the National Bureau of Standards for continuing the development of their instrument. This was described by Curtiss at the American Meteorological Society meeting in Indianapolis in December, 1937.

With regard to the other three types of radio meteorographs the Weather Bureau set up a program with two chief objects in view; first, to maintain close contact between the manufacturers and the bureau personnel making the observations; and second, to operate a station far distant from the manufacturer. In accordance with that dual program daily radio meteorograph observations were begun at the Weather Bureau Airport Station, Burbank, Calif., September 1, 1937, and continued to June 30, 1938. The instrument used there is known as the GALCIT type and was developed at the California Institute of Technology. These meteorographs are calibrated by the contractor in Pasadena and delivered to the Burbank station in small lots so that an instrument is available each day. The soundings are made as nearly as possible at the same time as the airplane observations at San Diego Naval Air Station, so that comparisons of the data can be made.

At the Boston Weather Bureau Airport Station daily radio-meteorograph observations were begun October 1, 1937, to continue to June 30, 1938. The Harvard type instrument, developed at Blue Hill Observatory, is being used there While close contact between the bureau personnel and the contractor in Cambridge, Mass., is also possible at Boston, the arrangements there require the instruments to be calibrated by the Weather Bureau instead of by the contractor. This was done in order to determine which plan might be best for future policy. Prior to the discontinuance of the Army airplane observations at Boston on December 31, 1937, these soundings were made at the same time, for comparative purposes.

In connection with an investigation of the structure of Polar Continental Air and the development of Cold Waves in North America, authorized under the Bankhead-Jones Act, the Weather Bureau began daily radiometeorograph observations at Fairbanks, Alaska, on October 7, 1937, to continue to March 15, 1938. The instruments used there are known as the Weather Bureau type and are manufactured in Baltimore. They are shipped to Fairbanks in monthly lots, where they are calibrated by bureau personnel. Under this plan, the practicability of transporting the instruments long distances and of using them under severe weather conditions, is being determined. Airplane observations are made at Fairbanks every third day for comparison with the radio-meteorograph data.

At the Central Office of the Weather Bureau in Washington, all of the various types of radio meteorographs are being tested and an attempt is being made to develop the most suitable calibrating and receiving apparatus, evaluation methods, launching technique, etc. A specialist in this field has now been added to the Central Office staff.

The observations made at the three stations mentioned are promptly evaluated and data for the meteorologically significant levels transmitted by radio to Washington, and to other stations, where they are charted and analyzed in conjunction with the regular aerological reports.

TABLE 1

	Burbank			Boston			Fairbanks		
	0°–1°	1°–2°	>2°	0°–1°	1°–2°	>2°	0°–1°	1°–2°	>2°
September	35	25	40	–	–	–	–	–	–
October	35	22	43	21	25	54	37	11	52
November	31	22	47	45	26	29	39	10	51
December	27	30	43	37	28	35	26	24	50
Total	32	25	43	34	27	39	34	15	51

During the first 122-day period at Burbank, a total of 97 radio-meteorograph records was obtained. Of these, 87 percent exceeded 5 km., 42 percent exceeded 10 km., and 13 percent exceeded 15 km. The maximum height attained at Burbank was 19.5 km.

During the first 92-day period at Boston, a total of 77 radio-meteorograph records was obtained. Of these, 87 percent exceeded 5 km., 25 percent exceeded 10 km.. and 4 percent exceeded 15 km. The maximum height attained at Boston was 22.2 km.

During the first 86-day period at Fairbanks, a total of 60 radio-meteorograph records was obtained. Of these, 75 percent exceeded 5 km., 13 percent exceeded 10 km., and none reached 15 km. The maximum height attained at Fairbanks was 12.9 km.

By comparing the temperatures indicated by the radio meteorographs with those shown by the airplane observations at the significant levels of the latter, the percentage frequencies of the differences given in Table 1 were obtained. (Because of the distance between Burbank and San Diego, the data below 1 km. at these two stations were not included in this comparison.)

The relative humidities as shown by the airplane and radio-meteorograph observations were compared in the same way as the temperatures, the humidity data being classified separately for temperatures above 0°C. and for all temperatures. The percentage frequencies of the differences between 0 percent and 5 percent relative humidity for Burbank were 31 percent for temperatures above 0°C. and 30 percent for all temperatures; between 5 percent and 10 percent relative humidity, 27 percent for temperatures above 0°C. and 26 percent for all temperatures. The corresponding values for Boston were 52 percent and 32 percent, 18 percent and 20 percent, and for Fairbanks 10 percent and 35 percent, 10 percent and 22 percent, respectively.

Before conclusions can be drawn from these results, however, a number of factors must be taken into account. These include the inexperience of personnel in the technique of making regularly scheduled observations of this kind; differences in time, in some cases, between the airplane and radio-meteorograph observations; differences in the courses taken by the airplane and the balloon and therefore possible differences of the air mass encountered.

TABLE 2

Place	Number of Observations	Percentage Returned
Omaha, Nebr.	306	92
St. Louis, Mo.	115	94
Royal Center, Ind.	80	91
Dallas, Texas	77	83
Ellendale, N. Dak.	64	91
Groesbeck, Texas	44	84
Broken Arrow, Okla.	34	76
Huron, S. Dak.	26	92
Avalon, Calif.	23	65

It would be desirable to obtain comparisons by sending aloft the various types of radio meteorographs simultaneously from the same place, with recording, *i.e.*, non-radio meteorographs attached to the same balloon. This should be done for a sufficient period to obtain soundings in all types of weather from some inland station where it is likely the non-radio meteorographs will be found and returned.

It is necessary to formulate a program now for the fiscal year, beginning next July. In view of the promising results being obtained and because of the great value of the data to be derived from these observations, it is hoped to increase the number of stations to six. To do this, it will be necessary to replace airplane with radio-meteorograph observations at some points, since additional funds were not made available for this work. An important factor in this connection is the large percentage of instruments which will be found and returned at favorably located stations. This should reduce the cost materially, provided the instruments can be made so that they will not be too greatly damaged upon striking the earth. The percentages of returns in some of the past sounding-balloon series made in this country with non-radio meteorographs are given in Table 2.

Institute Notes

Branches

The newly organized Seattle branch of the Institute held its first meeting on April 7, 1938. At the second meeting on May 10, the following officers were elected: president, Charles W. Morris; vice-president, Fred S. Eastman; secretary, Robert G. Busch; treasurer, Ellsworth A. Schaal. The membership of the branch is about 125.

The following papers have been presented in conjunction with the meetings.

April 7

Ralph Cram, Boeing Aircraft Company, "Flutter."
Jack Doyle, Boeing Aircraft Company, "Vibrations."

May 10

W. A. Reeves, General Electric Company, "Superchargers."
E. T. Allen, "Flight Testing."

June 30

E. G. Emery, Jr., Boeing Aircraft Company, "Plastics in Aircraft."
E. A. Ferguson, Boeing Aircraft Company, "Water Handling Characteristics of Aircraft."

Other Branches of the Institute report favorable progress and several meetings are scheduled. Accounts of these meetings will be given in succeeding issues.

Necrology

Harry H. Wetzel

Harry H. Wetzel, one of the Founder Members of the Institute, died on July 5, 1938, at his home in Santa Monica, California.

Mr. Wetzel was born in Tamaqua, Pennsylvania, Sept. 18, 1888. He was the son of Louis L. and Elizabeth Reed Wetzel. He attended the Albright Preparatory School and was graduated from Pennsylvania State College in 1914 with the degree of Bachelor of Science. For two years after graduation he was general manager of the Ferro Machinery and Foundry Company in Cleveland.

He left the Ferro Company in 1916, became assistant to the chief of aircraft production, United States Signal Corps, and was assigned to inspection duty at the Curtiss Airplane Company. He continued as an airplane production engineer for the army in Boston, Washington, and in the West for the duration of the War. In 1918, he became general manager of the Liberty Iron Works at Sacramento, California, and later of the Malleable Iron Company, Chicago.

Mr. Wetzel joined the Douglas Aircraft Company in 1922 as vice-president and general manager. He was a director of the Los Angeles Chamber of Commerce and was president of the California Air Industries Association.

Mr. Wetzel's career for the past sixteen years has been intimately associated with the successful growth of the Douglas Aircraft Company. Its achievements have been due in a large measure to his foresight and business ability. He was active in all causes which had as their object the furtherance of aeronautical development in the United States.

Book Reviews

(*continued from page 409*)

The gainful activities possible for the lower classes of pilots are enumerated.

The second monograph describes the duties, qualifications, salaries, and opportunities for positions (exclusive of piloting) connected with airline operation, airplane manufacture, and the government agencies.

The person looking for steady and stable working conditions is advised against entering Aeronautics. Rapid changes in design and government regulations make it necessary for workers in all branches to adapt themselves quickly to new conditions. On the other hand, this same instability makes for rapid advancement for those who are well qualified.

Sample courses of instruction for mechanics and dispatchers are given. For each position listed, the opportunities for advancement to the higher positions are given.

Flugzeug-Typenbuch, Ausgabe A, 1937–38; compiled by Dipl. Ing. Helmut Schneider; Herm. Beyer Verlag, Leipsig 0–5; 636 pages.

The book has the sub-title "A Handbook of the German Aeronautical Industry." It is a collection of the aeronautical products manufactured in that country and includes almost every conceivable application. The book comprises 20 parts and a complete index. The various parts are devoted to: descriptions and characteristics of planes, gliders and kites, airplane engines; descriptions of propellers variable pitch hubs; safety devices, including parachutes, oxygen apparatus, rubber boats, etc.; flight instruments, including, in addition to the standard instruments, special devices such as a four-element oscillograph actuated by pressure or electrical impulses; navigation instruments including special slide rules for calculating the various quantities; engine instruments; various special devices and materials such as undercarriage retracting systems, safety glass, etc.; motor accessories and parts; electrical appliances, fittings, batteries; materials, including the properties of various light alloys and synthetic materials; materials testing machines; testing apparatus such as strain gages for use during construction; instruments for use in connection with flight tests; apparatus for detecting flaws in materials, castings, etc.; apparatus for demonstrating aerodynamic phenomena, including apparatus for visualizing stream lines, simple balances for measuring aerodynamic forces, and small wind tunnels; tools and fabricating machines; and airport equipment, including meteorological instruments. The text is in German but the many photographs and tables are more or less self-explanatory.

Books Received

Trunk Air Routes of Europe, Shell Aviation Department, London, 1938; 447 pages.

Model Aeronautics Handbook, 1938, by Frank Zaic; Model Aeronautics Publications, New York; 192 pages.

The Cracking Art in 1937, by Gustav Egloff, Martha M. Doty, and Jane F. Jordan; Universal Oil Products Company, Chicago; 1938, 387 pages.

AERONAUTICAL REVIEWS

These brief reviews of recent articles on aviation subjects are published by the Army Air Corps for the information of its officers, and are printed here each month by permission of the Chief of the Air Corps.

Aerodynamics

A Model Flies Entirely Alone in the Saint-Cyr Tunnel. M. Victor. Automatically stabilized airplane model, designed and tested by R. Hirsch, is protected from gusts by a simple use of aileron operation. An auxiliary surface placed in the same conditions as the main wing acts as a servo-motor pilot of the aileron. Aileron along the entire length of the wing is in two articulated parts one over the other according to the design of L. Peyret. Usual empennage is replaced by a lighter one with two fins. Above the horizontal tail plane a small auxiliary profile is attached by a control to the movable flap of the elevator and serves as a dashpot to dampen vibrations in dynamic tests, as well as a pilot plane for the tail flaps. Ailerons are connected to the tail surfaces. Long discussion of the principles, designs tested, and results of static and dynamic tests. Les Ailes, May 26, 1938, pages 8–9, 4 illus.

Experimental Research on Aerodynamic Actions of an Oscillating Wing. P. Cicala. Apparatus and arrangement used in experiments on the behavior of aerodynamic moments and forces resulting from translational oscillations. Comparison of experimental data with theoretical calculation, previously reported, shows considerable discrepancy traceable to the fact that theory is based on use of an infinite span. In a comparison of results of Turin laboratory tests with theory, where account was taken of the finite span, the discrepancy disappeared almost completely. Short abstract from L'Aerotecnica, December, 1937. Aero Digest, June, 1938, page 96.

The Vibrations of a Wing Increase Its Lift. Curious effect shown by a wing in vibration during aerodynamic tests carried out by M. Denis at the Institut de Saint-Cyr. New form of additional lift, entirely unsuspected, offers an explanation for irregularities proved in practice, as for example, the qualities of certain biplanes when a wing unit was out of order, and the impossibility of attaining the same performance with airplanes of a series as with the prototype. Model of a wing of the Nieuport seaplane designed for the Schneider Cup and having a NACA-M.6 biconvex profile was mounted on a polargraph. When wind speed was increased the vibratory phenomena always appeared to start at the same angle of incidence and were maintained further. Frequencies of 30 to 40 periods per second were measured on the vibrating model with the stroboscope. Tests are described and the vibratory effect compared with the phenomena of small wing movements studied by M. Budig. Les Ailes, May 12, 1938, page 7, 2 illus.

The Estimation of Pipe Delivery from Pitot Tube Measurements. A. Fage. It is shown by formulas that usual assumptions do not hold when flow is turbulent. Account should also be taken of the fact that total head registered by a pitot tube in a region of total pressure gradient is not associated with geometric center of the mouth of the tube, but with an effective center displaced from the geometric toward the region of higher total head. Author assesses the order of error to be expected when the usual relation is used to predict rate of delivery from measurements taken at a section where a state of fully developed turbulence exists. Formulas are developed for turbulence and total pressure gradient corrections. Communicated at the suggestion of the British Aeronautical Research Committee. Engineering, June 3, 1938, pages 616–617, 2 tables, many equations.

Aircraft Design

First Tests of the Budig Airplane with Beating Wings. Results obtained with the Budig airplane with beating wings which utilize the aerodynamic effects of oblique attack. When the wind reaches the profile with a lateral deflection, the breaking away of the flow is decreased at the same time that the depression at the leading edge increases. In a wind of 10 to 20 meters per second there were three beatings per second, each wing having an amplitude of 50 cm. Displacement of the center of gravity of each wing during the beatings necessitated a dynamic balancing which was obtained by a counter weight placed inside the wing tips. Short note. Les Ailes, May 12, 1938, page 9, 1 illus.

Airplane Performance Calculations by Means of Logarithmic Graphs. I. H. Driggs. Paper and discussion by D. Biermann and E. G. Reid. S.A.E. Jour. (Trans.), June, 1938, pages 253–262, 11 illus., 5 tables, 13 equations.

Autostability of Airplanes Obtained by Means of the Constantin Wind Vanes. M. Mottez. Influence of the vanes on the different parameters of the equations for longitudinal stability; representation of autostability with the vane on the usual curves obtained in the tunnel and on their prediction by Marchal, Simon, and Delluc; adaptation of piloting by the decalage of the vane on a light airplane; and summary of the problems imposed by use of a curved flap controlled by a vane to assure the continuity of lift in gusts. Paper presented before the Cercle d'Études Aérotechniques, and discussion following it. L'Aéronautique, Supplement, April, 1938, pages 50–52, 5 illus.

Interferences and Controls. M. S. Ducout. Principal control plane supports an auxiliary plane so articulated to it that for all movements of the principal plane with respect to the support there is a corresponding movement of the axuiliary plane with respect to the principal plane. This arrangement can also be used for effects such as keeping the incidence constant and automatic stabilization.

In the first issue possible combinations of the elements are discussed with stability curves and equations, including: a plane articulated on a fixed support with the axis in front of the center of pressure; articulation of the plane at the rear of the center of pressure; a plane articulated on an arm on a fixed support and directed in the same direction as the relative wind; and a connection between plane and fixed support such that when the arm turns in a certain direction with respect to support, the plane turns in an opposite direction and at a very large angle, and arm carrying the plane articulated to it is directed in a direction opposite to the relative wind.

In the second issue these arrangements are applied to wings for reducing vertical accelerations due to gusts, and to control surfaces and to the blades of rotating wings. L'Aérophile, April and May, 1938, pages 87–89 and 112–113, 32 illus.

A Method of Calculating Seaplane Take-Off. V. Outman. Method of calculation described not only enables the computation of time and distance but also offers a means of studying the effect of various factors including those influencing trim. As an example take-off is calculated for a hypothetical flying boat having a gross weight of 150,000 lb., wing area of 5000 sq. ft., hull beam of 14 ft. and mean aerodynamic chord of 24 ft. Aero Digest June, 1938, pages 53–54, 59–60, 10 illus., 3 tables.

Possibilities of Vertical Flight at Low Speed. S. Pivko. Results obtained by the author in his laboratory experiments show the possibilities of take-off, either from ground or water, of an airplane the propeller of which is located above and in front of the wing, the propeller axis being suitably inclined.

Power, weight, and the power-weight ratio of some new French pursuits and bombers are given. The author believes that under certain conditions all these airplanes can take off from a place and eventually remain immovable in the air if the following are provided: a reducing gear or speed reverser placed between motor and propeller shafts, the reverser permitting variation of the propeller r.p.m. at full throttle; variable-pitch propellers particularly studied for operation at a fixed point and slightly displaced; and an advantageous arrangement of propellers with respect to the wing to profit by the aerodynamic reactions due to the propeller slipstream.

For flight at low speed, it is calculated that an airplane using the reducing gear permitting operation at two different speeds of rotation would take off and mount vertically, full throttle, with a speed about 2 meters per second corresponding to 1900 r.p.m. of the propeller. For horizontal flight cruising speeds around 300 km./hr. and more could be obtained corresponding to around 1100 r.p.m. L'Aéronautique, L'Aérotechnique Sup., March, 1938, pages 33–35, 8 equations.

Sport Plane Design—Winner of the 1937 Continental Trophy. Conquer-Aire two-place monoplane designed by G. H. Tweney and winner of the 1937 competition sponsored by Continental Motors Corporation. Aero Digest, June, 1938, page 71, 2 illus.

Stress Analysis and Structures

Advantages of the Tubular Spar Wing. R. Voght. Discussion of the tubular-spar wing is given by the Chief Engineer of the Hamburger aircraft company. Aero Digest, June, 1938, pages 72, 75, 2 illus.

Photoelastic Analysis of Stress Concentration for Beams in Pure Bending with a Central Hole. J. J. Ryan and L. J. Fischer. Test apparatus and procedure, stress concentration factor in bending, compression and tension, and rules for design of rectangular beams with centrally located holes under pure bending. Franklin Inst. Jour., May, 1938, pages 520–526, 15 illus., 1 table, 8 equations.

Aircraft Accessories

Aviation Equipment—Control of Airplane Wheel Brakes. A.E. hydropneumatic control is composed of an aircontainer, a regulator for regulating inlet pressure to the control valves, distributor permitting regulation of inlet of air in the control as desired and another permitting differential braking and control of the airplane on the ground, and "hydropumps" or hydropneumatic cylinders which, transforming air pressure into hydraulic pressure, transmit it to the control pumps of the brake shoe. Long description in both French and Jugoslavian. L'Aérophile, May, 1938, pages 108d-108f, 9 illus.

Hydraulic Vibration Absorbers for Airplane Controls. Repusseau automatic braking arrangement for the controls of movable control surfaces. Long description covers: construction and operation of the hydraulic vibration absorber; law of motion; study of liquid to be used in the absorber; adaptation of shock absorbers; methods of mounting hydraulic vibration absorbers on an airplane; special equipment including vibration absorbers having different action and transmission rods dampened for a limited force; vibration absorbers for lower flaps, rotating wings or lifting propellers; adaptation of an autobraking arrangement for blades of an autogiro; and verification of the braking of the autoresistant vibration absorber. Very long article. L'Aéronautique, Supplement, April, 1938, pages 41–49, 22 illus., 2 tables, many equations.

Technical Notes. Durandeau has designed a method for permitting the amplitude of the movements of the controls to be varied in function of airplane speed, in such a way as never to produce dangerous overloads at large ranges. Brief reference. Les Ailes, May 26, 1938, page 7.

Advantages of High Pressures in the Oleo-Pneumatic Controls. Oleo-pneumatic shock absorbers for landing and tail wheels and hydraulic controls which are described are based on the patents of J. Mercier and are produced by the Olaer firm, part of the French General Electric Company. Light weight of the oleo-pneumatic controls is due to use of a liquid under a very high pressure (250 kg./sq. cm.) forced by an automatically-regulated micro-pump in a jack of very small dimensions. Rapidity of operation is assured by an accumulator of oil under pressure which compensates the relatively small delivery of the micropump. Pump weighs only 1 kg. and is a drum with six pistons. Delivery at 2500 r.p.m. is 2 liters per minute and power absorbed is $^1/_4$ hp. Les Ailes, May 19, 1938, page 7, 4 illus.

Auxiliary Tail Wheel. New heavy-duty steerable tail wheel for airplanes in the heavier brackets among light aircraft. Flexibility in steering is obtained through use of a rubber shock chord linkage between rudder post control arms and wheel yoke. Few details. Aviation, June, 1938, page 49, 2 illus.

Technical Note. Rideau and Ducret have developed an antifrost glass windshield. Central part of the Triplex glass contains cellulose acetate Imbedded in its depth is a parallel network of heated nickel-chrome wires of 0.05- to 0.1-mm. diameter with a total spacing of 4 mm. Viewed from a distance of 1 meter the wires are practically invisible. Point of supply, contact and pilot lamp are fixed directly on the glass. Two examples are being tested by Air France. Brief note. Les Ailes, May 19, 1938, page 8.

Technical Notes. Siemens automatic equipment for control of elevator movements limits the stroke in function of speed and is somewhat of a valve for the accelerations. A pitot tube is connected to a manometer capsule operating a piston valve forming a distributor. A spring cushions the equipment and prevents perpendicular movements. Oil pump has a reservoir and a discharge valve placed in shunt which feeds through the distributor a servo motor, the spindle of which carries a pulley which travels under the control lever of the elevators. Short description preceded by a reference to equipment designed by E. Billocque for stabilization of the elevator at large angles of incidence, comprising a small plane mounted in front of the fuselage. Les Ailes, May 19, 1938, page 8, 1 illus.

Aircraft Accidents

The Belgian Stratospheric Transport Crashed on the Ground During the Test. R. F. Gillyns. Short description of the Renard stratospheric transport designed to carry 20 passengers and crew of three at a cruising speed of 450 km./hr. at 7000 meters, and a few details of the accident on its first test flight. The pressure cabin, which should protect the occupants in case of accident, may have broken into two parts and been pierced by the engine. L'Aérophile, April, 1938, page 90.

The Four Winds. A Wellesley caught fire in the air on May 13. Of five machines attached to the Long-Range Flight this is the second to be lost. Flight, May 19, 1938, page 488.

The Airplane and the Air Eddies. J. Thoret. Air eddies and cases of airplane accidents considered due to them. Rev. de l'Armée de l'Air, April, 1938, pages 425–432, 2 illus.

Another Fire Problem. The Vickers Wellesley which recently burned and crashed was not one of the five special Wellesleys for long-range flying but was one in which a special power plant installation was being tested. No explanation of the cause of the accident was forthcoming but the pilot's version of the accident is given. Brief note. Aeroplane, June 8, 1938, page 723.

Aircraft Testing

New Airliner Flies 63,875 Miles Without Leaving Hangar. Tests of the Douglas DC-4. "Reduced to mileage, the 'indoor flights,' as recorded in load applications and vibration tests, were sufficient in force and duration to have taken the big plane nearly three times around the world." Special methods and structures designed for tests of deflection in outer-wing panels of the plane, and for application of loads encountered in the high-angle-of-attack position are briefly described. U.S. Air Services, June, 1938, pages 23–24, 1 illus.

Photographs showing methods of static testing with brief explanations. Aviation, June, 1938, pages 32–33, 5 illus.

Aircraft Performance

Gliding into the Airport. A. H. Blaisdell. Technical aspects of the prelanding glide which comes within the immediate environment of the airport. Graphs given are based upon the flight performance of a low-wing monoplane having a wing area of 145 sq. ft. Angle of free glide, gliding (or air) speed and "air run distance" are discussed. Aviation, June, 1938, pages 30–31, 65, 6 illus.

Aircraft

Autogiros in the U. S. Army. Six Kellett autogiros of a new type delivered to Patterson Field for use in an "Autogiro transition flying training course—are much more powerful than the Rotas used by the R.A.F. and are characterized by a very neatly faired pylon for the rotor blades." Brief reference. Second note gives a few details of the Bell XFM-1. Flight, May 26, 1938, page 534.

Civil Aviation. Volland V-10 light two-seater (Train 6, CO1 60-hp. engine, maximum speed 170 km./hr.). Guerchais-Roche Type 25 two seater (Regnier 4.D.O. 60-hp. engine, 155-km./hr. speed). Canadian Sekani 45–80 A transport (two Pratt and Whitney Jr. SB. 400-hp. engines, maximum speed 325 km./hr. at 1520 meters). Timm 840 transport with tricycle landing gear (two Whirlwind R 975 E 420-hp. engines, maximum speed 338 km./hr., range 1350 km.). Cessna 38 Airmaster Touring airplane (Warner 50 Super Scarab 145-hp. engine, maximum speed 235 km./hr.). Descriptions, characteristics and performance. L'Aérophile, April, 1938, pages 79–82, 9 illus., 4 tables.

Short Technical Notes. Savoia-Marchetti S-75 18-passenger transport; the Rogozarski SIM XI single-seater trainer and acrobatic airplane; and retractable landing gear of the Heinkel He 70, He 112 V 1, He 118, He 111, and He 116 airplanes. Short descriptions. Luftwissen, April, 1938, pages 141–146, 12 illus.

Single-Engined. Douglas D.C.3 of the Czechoslovakian transport company was satisfactorily flown 1½ hours on one of its Cyclone G engines. The airplane was carrying a crew of four, seven passengers and 900 lb. of freight. When an oil-tank vent plug was lost, all the oil drained out and the starboard engine switched off. Brief note. Flight, May 26, 1938, page 518.

Light Airplanes. French Paul Aubert PA-20 two-seater (top speed 186 km./hr. with a Train 60-hp. engine and 220 km./hr. with the Regnier 90-hp. engine). Taylorcraft two-seater sport airplane (Continental A-40-4 40-hp. engine, top speed 146 km./hr.). Fleetwings Sea Bird 4-seater amphibian of stainless steel (Jacobs L.5 285-hp. engine, top speed 240 km./hr.). Bucker Bu-180 Student two-seater sport and training airplane (Walter Mikron II 55–60-hp. engine, top speed 175 km./hr.). Construction, characteristics and performance. L'Aérophile, May, 1938, pages 103–105, 8 illus., 4 tables.

The Yugoslav Aero Show. New military aircraft shown for the first time include: Breda 88 twin-motor fighter (two 14-cylinder aircooled engines probably giving total of 2000 hp., high wing loading) which holds the world's speed record over 100 km. at 554 km./hr. and has three forward fixed large bore machine guns; Macchi-Castoldi 200 single-seat low-wing prototype monoplane (14-cylinder radial engine, speeds rumored in excess of 350 m.p.h.) which has two large-bore machine guns firing through propeller disk; and the PZL 37 high-speed metal midwing bomber (two 9-cylinder engines, probably Pegasus, supposed maximum speed 290 m.p.h. with bomb load of nearly 5000 lb.). Few details of these airplanes and brief review of other exhibits. Aeroplane, June 8, 1938, pages 722–723, 4 illus.

Jugoslav works are reported to have the license to manufacture the Hawker Fury, Blenheim, Hurricane, and Dornier Do.17 in addition to their own machines. Jugoslavian airplanes shown include: Ikarus IK-2 (860-hp. Hispano-Suiza Y engine, top speed 264 m.p.h.); Zmaj FP-2 two-seater trainer (420-hp. Gnôme-Rhône engine); Rogozarski R-100 single-seater aerobatic airplane (420-hp. Gnôme-Rhône engine); and Sim X (120-hp. Walter engine).

Photographs include the new Macchi C.200 single-seater fighter, Polish twin-engined PZL-37 bomber, and its bomb cells, and nose of the twin-engined Breda 88 fighter-bomber showing three fixed machine guns.

Mention is made of the new German Breuer 5-cylinder aircooled radial engine (2.24-liter capacity, 40/50 hp. at 2300/2500 r.p.m., compression ratio 6:1 for ungeared model, dry weight 119 lb., fuel consumption 265 gr./hp-hr.). Short references to aircraft and engines exhibited. Flight, June 9, 1938, page 561, 4 illus.

Account of Show in both French and Jugoslavian. L'Aérophile, May, 1938, pages 108a–108c, 11 illus.

Czechoslovakia

Avia 422 Airplane. Single-seater for training in aerobatics, especially inverted flight, has factors of safety of 18 in a dive and 9 for inverted flight for weight of 1000 kg. Airplane is powered by an Avia RK-17 355-hp. engine with special carburetor, and has a top speed of 270 km./hr. Characteristics and performance only. L'Aérophile, May, 1938, page 115, 1 illus.

Finland

S.I.L.I. (Finnish International Aeronautical Exhibition). Finnish Tammerfors aircraft, which are said to be most up-to-date, and the Swedish, German and British exhibits are reviewed, including engines, propeller, tires, armament, light-weight airplanes, and instruments. Finnish State factory is now concentrating on designing and building its own aircraft, a few details of each being given. Illustrations include: Arado 95 torpedo bomber floatplane, Heinkel 112 with wing cannon and fixed machine gun hatch open, Swedish Sparmann S.1 single-seater trainer, and the Armstrong-Siddeley two-stage blower epicyclic gear "seen uncovered for the first time." A second article describes the opening of Helsingfor Airport and exhibitions given by the Finnish Air Force. Flight, May 19, 1938, pages 484–487 and 498–499, 14 illus.

France

Airplanes in Test. First issue—Amiot 370 racing airplane (two Hispano-Suiza 12-Y 940-hp. engine) has made a flight of around 15 hours duration at an altitude of 6000 meters. Brief reference only to this airplane and to the following military aircraft: Loire-Nieuport 161 pursuit (Hispano-Suiza 12-Ycrs engine cannon with ⅔ reduction gear and Rateau variable-pitch propeller), attaining a speed of 470 km./hr.; Morane-Saulnier M.S.278 (Clerget 500-hp. heavy-oil engine); and Bloch 150 pursuit (Gnôme Rhône 14-No. engine). Photograph shows the LeO. H-46 combat seaplane being tested with new Mercier engine cowlings.

Second issue—Morane-Saulnier M.S.-405 No. 3 and M.S.-406 (Hispano-Suiza 12-Ycrs engine cannon). Romano 110 (two Renault 900-hp. engines). Marcel Bloch 550 prototype trainer of wood (Lorraine "Algol" engine). Nieuport 163-03 (Hispano-Suiza 12-Ycrs 860-hp. engine cannon). Brief references only to these military airplanes undergoing tests, as well as to the Potez 661 four-engined transport, LeO H-246 four-engined transport (four Hispano-Suizas giving 2760 hp.), and the Delanne flying model (Regnier 180-hp. engine) of a pursuit airplane with tandem wings. Les Ailes, May 26 and June 2, 1938, pages 7, 8 and 9, 1 illus.

Airplanes in Test. Bréguet 690 C-3 (two Hispano-Suiza 14-B engines); Romano 110 C.3 (two Renault 450-hp. engines). Morane-Saulnier M.S.405, fourth modern pursuit of the series (Hispano-Suiza engine cannon). Bloch 150 pursuit (Gnôme Rhône 14-No. engine) to be tested also with a Pratt and Whitney Twin Wasp. LeO-45 bomber (two Hispano Suizas). Marcel-Bloch 131, No. 3 of the series (two Gnôme Rhône engines). Amiot 340 bomber (two Gnôme Rhône 14-No. engines, speed of 455 km./hr.) to have new cowlings and a double fin to increase the efficiency of the rear defense, and with this equipment taking the number 350. Bloch 180 seaplane (two Gnôme Rhône 14 No. engines). Morane-Saulnier 278 (Clerget 14-FOO 500-hp. heavy-oil engine). Amiot 150 reconnaissance and bombardment seaplane (two Gnôme Rhône engines). Brief references only to these aircraft in test. Les Ailes, May 19, 1938, page 7.

Amiot 150 Float Seaplane. A. Frachet. Amiot 150 B.E., derived from the Amiot 144 bomber, can be used as a reconnaissance, bombardment and torpedo seaplane. Its structure is entirely of duralumin tubes. Powered with two Gnôme-Rhône 1065-hp. engines, the seaplane has a speed of 300 km./hr. There are six gun stations. In the nose a machine gun projects from a rotatable turret covering the entire front hemisphere. A retractable floor permits the gunner to escape by parachute if necessary. Long description of construction, armament, characteristics and performance. Les Ailes, May 12, 1938, page 9, 2 illus., 1 table.

André Mélin Climbed to More Than 6000 Meters in a Flying Wing. In a recent test of the Flauvel flying wing to determine its ceiling, the pilot reached an altitude of more than 6000 meters. The A.V.-10 with a 75-hp. engine easily reached a speed of 170 km./hr. Brief note. Les Ailes, May 19, 1938, page 3.

Caudron-Renault C.710 Light Single-Seater Pursuit Plane. P. Léglise. The C.710 is an airplane of wood which, with a 450-hp. engine and a total weight of 500 to 600 kg. less than the single-seater pursuits now in service, fulfills exactly the same missions and carries armament of the same order. The airplane is powered by a Renault 12 Roi 12-cylinder air-cooled inverted-vee engine giving 430–450 hp. with supercharger maintaining the power at 3600 meters. Two Hispano-Suiza cannons of 20-mm. caliber are mounted in the wings. Very long description of construction, armament and other equipment with drawings. L'Aéronautique, March, 1938, pages 43–48, 17 illus.

Farman 223 Four-Engined Bomber. Long-range bomber carries a crew of 5 to 7 men and is equipped with four Hispano 14-Ha engines of 1100 hp. Estimated maximum speed is 400 km./hr. at 2850 meters and range 2000 km. at 360 km./hr. Description of construction and armament, specifications and performance. L'Aérophile, April, 1938, page 75, 2 illus., 1 table.

Morane-Saulnier 405–406 Single Seater Pursuit. Morane-Saulnier M.S.405 pursuit is equipped with a Hispano Suiza 12 Ygrs engine cannon with 48/51° reduction gear, and the M.S.406 has the same engine with a ⅔ reduction gear permitting a considerable increase of speed. Engine power is 860 hp. at 4000 meters. Armament of the 406 consists of a 20 cannon fixed on the engine and firing through the propeller and two Chatellerault wing machine guns. Control of lever and resetting are pneumatic. Speed is given as 490 km./hr. at 5000 meters and time to climb to 5000 meters as 8 minutes. Long description with drawings of structure. L'Aérophile, April, 1938, pages 76–78, 9 illus.

Technical Notes. Marcel-Bloch 150 single-seater pursuit has been equipped with a Pratt-Whitney engine, the license for which was purchased by the preceding French Air Minister, and which has given very good results at Chalais Meudon. Brief reference. Les Ailes, May 26, 1938, page 7.

Germany

Berlin-Tokio in 50 Hours with Two Heinkel He-116. Two Heinkel He-116 transports (four Hirth 240-hp. engines) were flown to Tokio at an average speed of 270 km./hr. They were supplied to an air transport company in Japan. Brief note. Les Ailes, May 12, 1938, page 4, 1 illus.

Figures for the Do-17. Jugoslavia has ordered 36 Dornier Do.17s, more than 15 of which have been delivered by air from Friedrichshafen to Belgrade at an average speed of about 250 m.p.h. Eighty Gnôme Rhône 14 No. two-row radials of 1000 hp. were ordered for installation in the machines. Additional performance data for the Ghôme-Rhône-powered Do.17s are given. Flight, May 19, 1938, page 490a.

The Dornier Do-24 Military Flying Boat. A. Frachet. Three-engined long-distance reconnaissance and bombardment flying boat (three Wright Cyclone 1000-hp. engines), ordered for Holland, has a speed of 320 to 340 km./hr. and can cover 3500 km. with a total weight of 13,500 kg. Six have been built in Germany and 18 will be built under license by the Dutch industry. Long description of construction, armament, characteristics and performance. Les Ailes, June 2, 1938, page 9, 2 illus., 1 table.

Good Going. New Heinkel single-seater fighter in a recent test made by Major-General E. Udet is reported to have achieved a speed of 394.178 m.p.h. over an official course of 62 miles. A Junkers 90 of the "Grosser Dessauer" type was taken up to 30,700 ft. with a payload of more than 11,000 lb. "That is better than the fictitious record of the Boeing Flying Fortress as depicted in the 'Test Pilot' film." Brief note. Aeroplane, June 15, 1938, page 735.

Henschel Production. Henschel Hs.126 parasol general-purpose military monoplane is being produced in very large quantities in a very short time due to the pressing of most of the sheet-metal parts and extensive use of castings. There are about 3000 sheet-metal parts of which 1000 are pressed in dies. Fuselage comprises transverse frames of sheet metal and heat-treated Elektron castings. Short note. Flight, June 9, 1938, page 568d, 3 illus.

Something New and Strange. New Messerschmitt twin-motored fighter is in production. "With two Mercedes-Benz motors, originally rated at 1000 hp. at 1450 r.p.m., for take-off,—which, we understand, have been speeded up to give 1360 hp. (40.4 hp. per liter) each, these service-type machines have a speed, according to British calculation, of about 380 m.p.h. A special version of this machine with two motors tuned up to give about 2000 hp. each should do about 440 m.p.h. These machines are believed to have retractable triplane flaps which can be turned edgewise to create high drag and no lift. Rumored speed of about 443.3 m.p.h. is not considered extraordinary for this airplane." Brief note. Aeroplane, June 15, 1938, page 735.

The Four Winds. Hamburg Ha.139 seaplane "Nordwind" (low-wing monoplane with four Junkers Jumo 205 Diesels) has crossed the South Atlantic from Bathhurst to Natal, about 1700 miles, in 11 hours 11 minutes, this constituting a commercial speed record. Brief reference. Flight, May 19, 1938, page 488.

The Helicopters Are Coming. Development of rotary-wing aircraft is briefly reviewed with special reference to the Focke-Achgelis helicopter, the effect of which has been to seriously diminish official interest in the single-rotor gyroplane. Aeroplane, May 18, 1938, pages 611–612, 2 illus.

High Speeds and Venetian Blinds in Germany. Rumors of extraordinarily high speeds made by German military airplanes. Messerschmitt Bf.109C single-seater fighter (new Daimler-Benz liquid-cooled engine) is said to have a maximum speed of 444 m.p.h., at its rated height of about 13,000 ft., due to great increase in motor, power from 910 hp. to 1360 hp. for little increase in weight or capacity, to wings of thin section and reduced span, and to a fully-ducted thrust-giving radiator system. Take-off, stalling and landing speeds have been kept within reasonable service limits by Venetian-blind flaps capable of spilling all the lift suddenly and presenting large drag area when turned flat to the wind. Latest Dornier Do.17 is said to do 332.42 m.p.h. with a useful load of 1984 lb. Heinkel 111 bomber covered 621 miles at 313 m.p.h. carrying a useful load of 2205 lb. Speeds of three previous Do.17 versions are given as well as speeds of the Blenheim bomber and Savoia Marchetti S.79. Brief note. Aeroplane, May 18, 1938, page 594.

Junkers Ju-87 Two-Seater Bomber. All-metal low-wing monoplane bomber (vee liquid-cooled 680/950-hp. engine) designed for dive bombing, for transporting a load of bombs of 250 to 500 kg., and for acrobatic flying. Armament for defense and attack includes a fixed mechanically-operated machine gun in the right wing, a second fixed machine gun to be placed in the other wing, and a movable machine gun in the upper part of the fuselage firing towards the rear and in the air. Bombs are fixed under the fuselage in the rear of the front radiator and, at launching, a fork directs the bombs outside of the propeller field. Description but no figures or estimates of performance. L'Aérophile, April, 1938, page 78.

Teutonic Trio. Henschel He.126 general-purpose machine particularly suitable for observation (army cooperation) work due to its parasol layout; Junkers Ju.86K bomber (two Junkers Jumo engines) which equip a number of German squadrons; and the Dornier Do.17 bomber (two Daimler Benz inverted-vee engines) capable of over 280 m.p.h. Photographs only. Flight, May 26, 1938, page 534, 3 illus.

Great Britain

For Army Cooperation. Construction, armament, performance and characteristics of the Westland Lysander Mark I (Mercury XII 890-hp. engine, top speed 230 m.p.h., landing speed 52 m.p.h.) are described in detail and remarkable servicing facilities are pointed out. Cutaway drawing shows location of armament and other equipment and another two-page drawing shows constructional details. Handley-Page leading-edge slots extend over the entire span of the wings, inner portion being a lift slot and outer a normal tip slot. Wide speed range is attained largely by a combination of high wing loading and use of slots and flaps. Flight, June 9, 1938, pages 569–576, 17 illus.

Full description of Lysander I with cutaway drawing, and discussion of excellent results obtained by use of slots and flaps, working of which is fully automatic. Wing loading works out to nearly 23 lb./sq. ft., or nearly that of the modern fighter. Range is 600 miles at 150 m.p.h. Special stub wings can be fitted to the undercarriage legs above the wheel fairing to take bomb carriers. Lysander II has a Bristol Perseus 905-hp. engine. Aeroplane, June 8, 1938, pages 717–721, 8 illus.

Hawkers—With Differences. Hawker Henley Merlin-engined bomber modified for high-speed target towing and shortly to be issued to Armament Training Stations, and a modification of the Hawker Hind for high-speed parachute dropping. Speeds of about 320 m.p.h. are obtained with the Hind before release of the dummy. Static line is fitted to ensure clearing the structure. Photographs only. Flight, June 2, 1938, page 555, 3 illus.

The Revised Hampden. In the revised Handley-Page Hampden bomber, liberal application of slots and flaps combines with clean design and two Pegasus engines of the latest series to make the bomber "one of the fastest machines of its caliber in the world." Photographs only illustrating the new nose and referring to dihedral on the wings and revised gun positions. Flight, June 2, 1938, pages 543, 554, 2 illus.

The Short Sunderland. At least five Short Sunderland flying boats which have been developed from the Empire boat, have been completed. They represent a new class of four-engined long-range patrol reconnaissance and bombing machines now being developed by major powers. Power-driven gun turrets are installed in bows and stern, the front one sliding to permit mooring operations. Engines are probably of the new Pegasus XXII series having a take-off of 1010 hp. Few details of design as it differs from that of the Empire boat with photographs showing unusual hull bottom and nose and tail gun turrets. Flight, June 2, 1938, pages 554, 556, 538, 4 illus.

Photographs only of flying boat designed for cruises up to 3000 miles. Aeroplane, June 1, 1938, pages 660, 676, 4 illus.

On Types in the Royal Air Force. C. G. Grey. Sixty aircraft for the R.A.F. are discussed covering single-seater fighters, Army Cooperation, single-engined bombers, old twin-engined bombers, twin-motor trainers, modern bombers, flying boats, general-purpose types, trainers and communication types, aircraft of the Fleet Air Arm, target airplanes, and prototypes. References are made to the following prototypes: the Supermarine Spitfire (Merlin), Blackburn Skua (Mercury engine), Hawker Henley (Merlin), Fairey P.4/34 (Merlin), Bristol Bombay troop transport (Pegasuses of the most boosted type). Reasons are given for not putting these prototypes into production before. Aeroplane, June 1, 1938, pages 666–681, 654, 55 illus., 1 table.

Three New Vickers Military Aircraft: The Wellesley, Wellington and Venom. Wellesley is a two-seater long-range general-purpose bomber (Bristol Pegasus 925-hp. engine with two-speed supercharger, maximum speed 367 km./hr. at 5200 meters). Wellington twin-engined bomber (geodetic construction, two Bristol Pegasus XVII engines each giving 995 hp. for take-off) is noted for the heavy bomb load carried and has been produced in large numbers for the R.A.F. Venom single-seater fighter (Bristol Aquila A.E.3.S. engine developing 500 hp. at 2600 meters) is intended for day and night attack. Long description of Wellesley with characteristics and performance and comparison with the Russian A.N.T.25. Shorter descriptions of the Wellington and Venom. Rev. de l'Armée de l'Air, April, 1938, pages 465–474, 7 illus., 3 tables.

A Tricycle for the R.A.F. General Aircraft Monospar with tricycle undercarriage has been sold to the British Air Ministry for research. The Royal Naval Air Division are much interested in tricycles as a possible means of preventing machines from swerving off the deck after landing-on. Brief reference. Aeroplane, May 25, 1938, page 651.

The Torpedo-Bomber—A New Conception. Fokker T.8-W three-seater twin-engined machine (two 400/750-hp. engines) is designed for torpedo dropping and reconnaissance. Internal stowage for torpedo or bomb load is provided, release gear being electrically locked until trap doors are fully opened. Pilot has a fixed gun and radio operator has access to a second weapon on a shielded mounting at rear of the cockpit enclosure. Brief reference. Flight, June 9, 1938, page 568.

Hurricane Attitudes. "The Hurricane is the fastest aeroplane in ordinary squadron service in the World . . . and, because of the Edinburgh flight, must do about 340 m.p.h. We should like to see what it could do with small wings and slots and Venetian blind flaps." Photographs only of the Hurricane in flight. Aeroplane, May 18, 1938, pages 594–595, 3 illus.

A Long-Range Bomber Now in Service—The Armstrong Whitworth Whitley. Two-page cutaway drawing showing location of armament and other equipment of the Tiger-engined Whitley which is used by several squadrons of the R.A.F. and has a top speed of over 200 m.p.h. with an impressive load of bombs. Sketch of the nose of the later Whitley IV (Rolls-Royce Merlin engine and ejector-type exhaust manifolds) is included. Flight, May 26, 1938, pages 528–529, 3 illus.

New Aircraft. Westland Lysander Army-cooperation monoplane (Mercury XII moderately supercharged engine, maximum speed 220 m.p.h. at an all-up weight of 5920 lb., other performance figures being given.) Fairey P.4/34 light bomber (1050-hp. Merlin engine, top speed 283 m.p.h.). Hawker Henley target-towing aircraft. Vickers Wellington (Pegasus, Rolls-Royce Merlins or Bristol Hercules engines probably with two-speed superchargers. New Reid and Sigrist monoplane three-seater trainer (two Gipsy Six engines, speed probably over 200 m.p.h.). Few details. Flight, May 26, 1938, page 533.

New Specifications of Twin-Motor Aeroplanes. Complete specifications for the Bristol 142M Blenheim (28/35), having a maximum speed of 279 m.p.h. at 15,000 ft. Aeroplane, May 18, 1938, page 612, 2 illus., 1 table.

Quantity Production at Filton. Long description of methods employed in building the Bristol Blenheims for the R.A.F. Flight, Aircraft Engr. Sup., May 19, 1938, pages 33–38, 11 illus.

Whitleys I, II, III, and IV. Whitley I (775/805-hp. Tiger IX engines. maximum speed 192 m.p.h. at 7000 ft.). Whitley II (Tiger VIII engines with two-speed superchargers giving 805/845 hp. at 6250 ft., 780 hp. at 14,250 ft. and 920 hp. for take-off; maximum speed 215 m.p.h. at 15,000 ft.). Whitley III (same engines) will incorporate improved bomb stowage which necessitates fuselage structural alterations. Whitley IV's performance (Rolls-Royce Merlin engines) should undergo a further "bump-up" and altitude speed should be 15 to 20 m.p.h. better. Brief note. Flight, May 19, 1938, page 489.

Vindication. Full-load separation trials of the Short Mayo composite aircraft, the Mercury being loaded to 20,800 lb. Take-off was accomplished in about 17 seconds in practically no wind, separation took place smoothly with machines in perfect trim, and fuel-discharge tests were entirely successful. At no time did the gasoline tend to reach any part of the machine where it could be the slightest fire danger. Flight, May 19, 1938, pages 483, 488, 1 illus.

Japan

The Japanese Long-Distance Airplane "Wings of the Century" Beat the Record for Distance over a Closed Course. "Wings of the Century" has a wing span of 27.75 meters, 87 square meters surface, and aspect ratio of 9. Prototype has been equipped with a 800-hp. Kamasaki 12-cylinder vee engine manufactured under German license, undoubtedly a B.M.W. engine. Maximum range calculated from the performance is 16,000 km. The airplane covered 11,658 km. in 68 hours 26 minutes at an average speed of 170 km./hr. Note dealing mostly with French records made previously. Les Ailes, May 26, 1938, page 5, 1 illus.

Holland

New Military Aircraft. Koolhoven F.K.56 two-seater reconnaissance airplane (Wright Whirlwind R975E3 420-hp. engine, top speed 300 km./hr. at 500 meters, range 800 km. at 1400 meters). Construction, armament, characteristics and performance. Luftwehr, May, 1938, page 211, 1 illus.

The Koolhoven F.K. 49 and F.K. 50. A development of the F.K.49, used for some years by the Royal Netherlands Army Air Service, has been built to the order of the Turkish government. Airplane is a four-seat twin-engined high-wing monoplane for air survey, charter or feeder lines. (Two Ranger V-770 B-4 12-cylinder inverted-vee aircooled unsupercharged 304-hp. engines, maximum speed 165 m.p.h.).

F.K.50 ten-seater twin-engined monoplane transport (two Pratt and Whitney Wasp Junior TB 840-hp. engines, maximum speed 165 m.p.h. with 8940-lb. load). Specifications and performance are given for both airplanes. Aeroplane, May 18, 1938, page 613, 4 illus., 2 tables.

ITALY

The Latest Savoias. Savoia-Marchetti S.75 24-passenger transport (three Alfa Romeo 126 R.C.34 750-hp. engines, top speed 228 m.p.h.), and the S.83 10-passenger transports (three of the same engines, top speed 264 m.p.h.). Characteristics, performance, and photographs. Flight, May 19, 1938, p. 490d, 6 illus., 2 tables.

New Flight Record. Record of Stoppani-Gorini in a Cant Z.509 (three Fiat A80 R.C.41 1000-hp. engines) at 403.424 km./hr. over 1000 km. and at 399.644 km./hr. over 2000 km. Brief reference. Luftwehr, May, 1938, page 214.

Some Fiat Impressions. Aero engines, bombers and fighters in production at the Fiat works. Italian tendency is to reduce armament of fighters to a minimum rather than multiply it as in the British Hurricane. Even the 300-m.p.h. Fiat G.50 in production normally has only two guns. Armament and other details of the Fiat C.R.32 single-seater biplane fighter and the B.R.20 bomber (two A.80 R.C.41 engines, top speed 267 m.p.h.) both in quantity production for the Regia Aeronautica, and a few details of the A-80 and A-74 engines. Flight, June 9, 1938, pages 565–566, 5 illus.

Caproni CA-310 Bomber. Caproni CA-310 light bomber is designed for training personnel in piloting high-speed bimotored bombers. Extremities of the wings are demountable in order to facilitate transport and repair in case of accident. Two Piaggio P.VII C.16 7-cylinder radial 430-hp. engines, maximum speed 346 km./hr. at 2250 meters, range 1055 km. at cruising speed of 323 km./hr. L'Aérophile, May, 1938, page 100, 2 illus., 1 table.

The Fiat G18V. Two-motored high-speed 21-seater commercial transport (two Fiat A80 R.C.41 supercharged 18-cylinder two-row radial 1030-hp. engines, top speed 249 m.p.h. at 15,250 ft., range 930 miles) has retractable undercarriage and split flaps. Characteristics and performance. Aeroplane, June 15, 1938, page 752, 2 illus., 1 table.

Differences between the Fiat G.18 and G18V transports used on the Italian England-Venice line and account of flight to Venice in the latter. Flight, June 9, 1938, page 579, 3 illus.

Fiat G.50 Single-Seater Pursuit Airplane. Fiat G.50 low-wing metal monoplane with retractable landing gear is powered with a Fiat A-74 R.C.38 engine developing 850 hp. at 3800 meters. Maximum speed is 470 km./hr. at 4000 meters. Few details of construction, characteristics and performance. L'Aérophile, May, 1938, page 101, 2 illus., 1 table.

POLAND

Polish PZL-37 Medium Bomber. PZL-37 four-seater all-metal medium-wing bimotored bomber armed with three machine guns and a load of bombs which can be placed entirely within the wing. Slots and flaps located on the under surface of the wing give additional lift. Maximum speed 460 km./hr. when powered with two Gnôme-Rhône 14-N-25 900-hp. engines. Construction, armament, characteristics and performance. Long description. L'Aérophile, May, 1938, pages 98–100, 2 illus., 1 table.

P.Z.L.37 Bomber. A. Frachet. Polish metal monoplane light bomber weighs 4225 kg. empty and transports a load of 4275 kg. With two Bristol Pegasus XX 918-hp. engines top speed is 440 km./hr. at 3700 meters, and range 1500 km. with 2200-kg. bomb load. With two Gnôme Rhône 14-N.25 900-hp. engines top speed is 460 km./hr. at 4600 meters and range 1600 km. with the same bomb load. Description of construction, armament, and performance with these engines as well as with two Bristol Pegasus XII 873-hp. engines. Les Ailes, May 19, 1938, page 9, 2 illus., 2 tables.

U. S. A.

Naval aircraft factory has just completed its first 100-per cent Government-built aircraft—185 training planes, 20 of them mounting 235-hp. NAF-R760 engines (Wright license). Forty-four scout observation airplanes (Curtiss SOC) and enough parachutes to fill about half the Navy's needs are in production. Brief reference. Aviation, June, 1938, page 54.

Brewster XF2A-1 Single-Seater Fighter. XF2A-1 single-seater midwing monoplane fighter for the U. S. Navy having a transparent canopy-top cockpit enclosure and a window in the bottom of the fuselage. Trimming tabs are provided on both elevators and rudder. Few details given refer also to the retractable landing gear and tail wheel, and accessibility of the Wright Cyclone engine and its accessories. Aero Digest, June, 1938, page 83, 2 illus.

Consolidated Looks Ahead. Preliminary study of a 300-passenger flying boat and a modification of the PBY, this latest version being an amphibian. Main float of the 200-ton flying boat is designed to retract up against the fuselage bottom and the outboard floats into the under side of the wing. Six 2000-hp. engines within the wings drive three-bladed 20-ft.-diameter propellers through extension shafts. Span 272 ft., wing loading 47.7 lb./sq. ft., cruising speed 300 m.p.h., and range 5000 miles. Few details. Aviation, June, 1938, page 41, 2 illus.

A Chat with Glenn Martin. Initial tests of a scale flying model of a new type of patrol bomber wanted by the U. S. Navy were very promising. Model represents a "gull-winged machine (not unlike the Short Knuckle-duster which was rather down on performance, due to the fact that the inner sections of the wings were virtually stalled in level flight) with corrugations in the upper hull plating." Twenty-two examples of the full-scale machine have been ordered. Characteristics of the Martin 166 bomber (Twin Wasps or Cyclones) are given.

American shipping companies are interested in flying-boat services and one is considering purchase of some Martin 157s developed from the 156 supplied to Russia, but having improvements and strengthened for an all-up weight of 70,000 lb. Boats weighing 250,000 lb. are visualized. Projected four-engined boat with a hull that is "easy on the wind tunnel" is illustrated. Flight, June 2, 1938, page 551, 2 illus.

The Four Winds. All-stainless-steel wing built by E. G. Budd Manufacturing Company for the new 300-m.p.h. Seversky pursuit is said to be a few pounds lighter and to have four times the rigidity of its aluminum-alloy prototype. New Seversky Super Clippers will be built of stainless steel. Brief reference. Flight, June 2, 1938, page 548.

Multi-Engined "Airacuda" Invades Pursuit Ship Field. "Certainly three years ahead of anything else in the aeronautics field with which it can be compared, it is comparable in its advanced design to the four-engined bombers which are now in regular combat use in the U. S. Army. Four-engined bombers are still several years from combat use in Europe. . . . So unusual is the 'YEM-1' (XFM-1) fighter, that it is believed that it definitely opens a new era in military aviation." Air Corps order for 13 and a few details are given for the "first fighter with a range comparable to that of a medium-sized transport." Science News Letter, June 11, 1938, page 387.

Place in the Air Predicted for "Windmill" Plane. Performance of the new autogiro recently demonstrated which took off in 25 ft. and landed almost literally on a dime. Few details and possible uses for the Army, Navy, Coast Guard and others. Science News Letter, June 4, 1938, pages 360–361, 1 illus.

Ryan Offers New Military Model. Ryan S-T-M military trainer (Menasco C4S 150-hp. supercharged engine) has a top speed of 160 m.p.h., cruising speed of 135 m.p.h., initial rate of climb of 1400 ft. per minute, and service ceiling of 21,000 ft. Short description. U.S. Air Services, June, 1938, page 32.

Short Spans. North American Aviation has been running tests on its Dragon bomber with new power plants, evidently expecting to get into a forthcoming competition for a bomber contract. Further delay in delivery of the O-47's is said to be due to the Army desiring to give each of the first three planes, already delivered, 100 hours in service flying before releasing production. Brief note. Western Flying, June, 1938, page 32.

Speed Burners. Racing airplanes being prepared for the Pacific International Air Races. Few details. Western Flying, June, 1938, page 13.

Swallow Coupe. Swallow Model C two-place monoplane (Menasco 125-hp. engine, top speed 145 m.p.h., and cruising range 450 miles). Short description. Aviation, June, 1938, page 35, 2 illus., 1 table.

Recent views of Bellanca's two-seater military Model 28–90 airplane powered with a Twin Wasp engine. Photographs only. Aero Digest June, 1938, page 13, 3 illus.

New Military Aircraft. Curtiss XP-37 single-seater pursuit (Allison 12-cylinder vee 1000-hp. engine with G.E. exhaust-driven supercharger, top speed 570 km./hr., range 1000 km., service ceiling 10,000 meters, speed of climb 1280 meters/min.). Construction, armament, characteristics, performance. Similar information is given for the Seversky Convoy multi-purpose airplane. The Seversky SEV-3 amphibian is illustrated on another page. Luftwehr, May, 1938, pages 211, 214, 3 illus., 1 table.

Air Transportation

Behind the Scenery. F. D. Bradbrooke. Account of a visit to Swissair's maintenance shop at Zurich, and references to maintenance methods for overhaul of Douglas D.C.2s, Wright Cyclone engines and Sperry Autopilots. Douglases using 87-octane gasoline for take-off and 77-octane to fly on are considered much more economical than the Junkers Ju.86 with Jumo heavy-oil engines, taking into account the maintenance of airframe and engines also. Aeroplane, June 8, 1938, pages 723–725, 5 illus.

Gumboots to Gondolas in 7½ Hours. Flt. Lieut. R. C. Preston. Account of a London-Venice trip on the inaugural flight of the Italian A L I airline, with comments on the twin-motor Fiat G18V 18-passenger transport used. Aeroplane, June 15, 1938, pages 739–740, 3 illus.

Baltic Terminal. Helsinki airport at Helsingfors, Finland, has two separate blind-approach lines and new control building. Description of airport and winter operations. Second article discusses plans for extension of Stockholm's airport, new blind-approach line, and A.B. Aerotransport's fleet. Flight, June 2, 1938, pages 548b–548c and 545, 9 illus.

The North Atlantic Service. Regular transatlantic air service in September was forecast by Colonel J. M. Johnson, Pan American Airways will then be in a position to handle mails and possibly passengers. Imperial Airways have not any equipment ready which could undertake such services. Germany has sought permission for use of American bases on 18 return flights this summer. Short note. Aeroplane, June 15, 1938, page 753.

Technical Problems of Commercial Air Transport. R. Stuessel. Technical problem of the Atlantic service, technical possibilities for decrease in costs, and characteristics and performances of standard airplanes and seaplanes in Atlantic service, and of new seaplanes and airplanes for Atlantic service. Concluded. Luftwissen, May, 1938, pages 175–180, 4 illus., 3 tables.

Trans-Canada Rubs the Lamp. D. Sayre. Development of Canada's new transcontinental airline, and details of the airway, flying equipment, and personnel training. Aviation, June, 1938, pages 21–23, 66, 68, 70, 7 illus.

Airships and Balloons

The Four Winds. Preliminary tests have been made with a new Soviet airship USSR-V-10 which accommodates a crew of eight and is powered by two 100-hp. engines. Brief reference. Flight, May 19, 1938, page 488.

An International Crime. An English point of view on the decision of the United States in regard to export of helium to Germany. Aeroplane, May 4, 1938, pages 520–521.

Navy Gets New Blimp. Goodyear-Zeppelin L-1 blimp (two Warner Super Scarab engines) is the Navy's smallest. It is to be used for training purposes and carries a crew of two and six passengers. Length 147.5 ft., capacity 123,000 cu. ft., maximum speed 59 m.p.h., and cruising speed 45 m.p.h. Brief reference. Aero Digest, June, 1938, page 17.

Balloon Race. Results of the race for the International Cup for spherical balloons starting on May 15 during the fair at Tours. P. Jacquet landed at Bubingen, Belgium, a distance of 504 km. Brief note only. Les Ailes, May 26, 1938, page 4, 1 illus.

Gliders

Soaring in Germany. M. E. Spire. Schlempp and Schleicher plants manufacturing Goeppingen Minimoa and the Rhoenadler and Kranich high-performance and training gliders are discussed and the constructions of the gliders are described in detail with drawings. Few details and photographs of the American SGU1–6 and 1–7 and the A.B.C. gliders are given in a second article. L'Aérophile, April, 1938, pages 83–86, 89, 18 illus.

Soaring Flight in Germany. E. Spire. Further details comparing methods used in the Schempp and Schleicher plants in the construction of gliders such as the Minimoa and Kranich. Fabrication and mounting of the fuselages and wings; positioning and gluing of the leading edge of the wing; covering with fabric and painting; products used; wing fittings and towing hook; acceptance tests; construction designs; and coefficient of safety. Concluded. L'Aérophile, May, 1938, pages 106–108, 15 illus.

Flight Without Engine. Delanne 30-P.2 two-seater glider having a fineness ratio of 28 has started its tests. Drawing only. Les Ailes, May 12, 1938, page 1, 1 illus.

Propellers

Birth of a Propeller. Processes in the manufacture of Curtiss-Wright electrical controllable-pitch propeller from rough forging to finished product. Photographs only. Aviation, June, 1938, pages 26–27, 14 illus.

Cord-Bakelite Airscrew Blades. DeHavilland hollow propeller blades molded in Bakelite reinforced with cord. Cords lie longitudinally, simulat-

ing closely the grain flow in duralumin blades, of particular importance at the root flange where blade is held against centrifugal load. Tensile strength is about 35,000 lb./sq. in. and shear strength in direction of cords is about 6000 lb./sq. in. DeHavilland is developing a 5000-size propeller with cord-Bakelite blades for the British Air Ministry. Flight, June 9, 1938, page 584, 1 illus.

Synthetic Resins are Developed for Airscrews. G. Abrahamson. New covering for wooden propellers, developed in collaboration with the British Air Ministry, consists of a fabric envelope treated with a special flexible synthetic resin of a rubbery nature pressed closely to the blades by a new hot molding process, providing a tough layer of protective material bonded very firmly all over the wood. Material is unaffected by ultra-violet light, oils, and gasoline and is resistant to moisture and weather conditions. Brief note from Industrial & Engineering Chemistry, News Edition, No. 4. Franklin Inst., Jour., May, 1938, page 615.

Miscellaneous

Operating Costs of Planes, Cars and Boats. L. de Florez. Comparative operating cost of two- and four-passenger cabin airplanes, two automobiles, and one motor boat. S.A.E. Jour. (Trans.) June, 1938, page 262, 1 table.

Aircraft Instruments

Link Model D. Link trainer developed largely for European use with the Lorenz landing system substituted for the radio range station. For effective use of this system certain instruments were supplied in duplicate for the instructor to convey to the pilot under the hood his position on his flight path and his altitude. Complete set of regular flight instruments are included permitting instruction in instrument flying. Aviation, June, 1938, page 49, 1 illus.

Navigational Refinements. In the Tyndale-Biscoe compass deviation card described small spaces are provided for entering deviations at intervals of 15° and 22½°, and all that portion of the card in which deviations are Westerly are shaded. Carroll Mercator plotting chart, also described, consists of a rectangular plastic board which will take pencil marks, and an arm with sliding pointer and pivot. Aeroplane, May 18, 1938, page 618, 1 illus.

Rate-of-Climb Indicator. Smith indicator consists of a sensitive differential pressure gage used with a capacity connected to the atmosphere through a leak device. Minute movements of a flexible capsule are converted into rotation of the pointer. It weighs 1 lb. 4 oz. and is made in two ranges, 0–2000 ft./min. and 0–4000 ft./min. Few details. Jour. Scientific Instruments, May, 1938, page 182.

Astronomical Navigation. Sqn. Ldr. E. H. D. Spence. Simple explanation of the principles, the Greenwich hour angle, and making use of the "Air Almanac." To be concluded. Flight, June 9, 1938, pages 568b–568d, 7 illus.

Automatically Controlled Blind Landings. Capt. G. V. Holloman. S.A.E. Jour., June, 1938, pages 13–18, 11 illus.

Miscellaneous Equipment

Boeing Clipper Beaching Gear. Kenworth welded steel beaching gear ordered by Pan American Airways for launching and docking of the 82,000-lb. Clippers. Members are built in the form of flotation tanks with airlocks and additional air tanks assure an excess buoyancy of about a ton at the water's surface. Few details. Aero Digest, June, 1938, page 87, 1 illus.

To Reduce Fire Risk. Suggested layout in an imaginary airplane for the Essex automatic fire extinguisher, and a few details of the system. Fire extinguisher uses methyl bromide and gives off a gas 3½ times the weight of air which smothers a fire very quickly. Extinguisher contains 5 lb. of fluid under a pressure of 150 lb./sq. in. provided by compressed nitrogen, and is automatically operated in a crash. Brief note. Aeroplane, May 25, 1938, page 650, 1 illus. Flight, June 23, 1938, page 623.

High Altitude Equipment

High-Altitude Equipment. Layout of the Avimo system of oxygen supply, oxygen heating, clothing heating, telephone and radio in a large aircraft for operation between 13,000 and 40,000 ft. Throughout the system patented by French Bronzavia Company, services are combined in a duplicated 13-mm. diameter conduit cable carrying twelve electric wires (for radio and heating of the suit and the oxygen supply), and the oxygen tube. Small 1-liter emergency cylinder carried individually contains sufficient oxygen for 25-min. breathing. Description of equipment. Flight, June 2, 1938, page 548a, 1 illus.

Parachutes

Italian Technique in Dropping Supplies from Airplanes. Method used by the Italian Army in Ethiopia. Equipment consists of a parachute similar to the Salvator parachute for pilots and operated automatically. Supplies are packed either in bags or in welded sheet-steel containers having four rubber feet for absorbing landing shock. Parachute has a lifting surface of 43.2 meters and is constructed of linen of high specific resistance. Description. L'Aérophile, May, 1938, page 98, 1 illus.

Photography

AERIAL PHOTOGRAPHY

Air Photography and Adequate National Surveys. O. S. Reading. Advantages of air photographic surveys, necessity for an adequate national survey, and requirements in regard to: control, cadastral-topographic maps and photographs, smaller scale topographic and base maps, nautical charts, provision for revising maps and charts, reproduction, organized distribution authoritative standards, and a planned program. Photogrammetric Engg. January-March, 1938, pages 11–29, 10 illus.

What Canada is Doing With the Aid of Camera and Aeroplane. A. C. T. Sheppard. Work of the Royal Canadian Air Force and other services in making surveys; air photogrammetry; details of the aircraft, cameras, lenses, camera mounts, auxiliary equipment, film and paper used; air photographic library and consulting assistance; air mapping services; flying instructions; ground control; mapping methods; and plotting instruments Photogrammetric Engg., January-March, 1938, pages 30–41.

Progress in High-Frequency Cinematography. R. Thun. Requisites of apparatus with optical compensation for making film exposures at high frequency both for demonstration purposes and for a measurable series of photographs, and the performance obtained so far. Time and group exposures, size of image and evaluation of photographs are discussed. Lens disks for the Thun time recorder are illustrated including disks with 16 and 64 round lenses, respectively, and with 84 rectangular lenses. V.D.I., June 4, 1938, pages 697–700, 8 illus.

Testing Apparatus

A Photographic Profile-Exposure Apparatus for Propellers and Model Wings. R. Kuhl and K. Raab. Apparatus which by a photographic method enables the testing of parts difficult to measure such as propellers and model wings. Design and operation are described in detail and usefulness of the apparatus is demonstrated by examples of profile exposures. Report of Goettingen Aerodynamic Institute. Luftwissen, May, 1938, pages 183–185, 8 illus.

Electronic Micrometer. With the new Carson electronic micrometer made by the Instrument Specialties Company measurements of dimensions to within 0.00005 in. may be made with no contact pressure and no human element in the setting. Few details. Automotive Industries, June 11, 1938, pages 780–781, 2 illus.

Materials

Materials of Aircraft Construction. H. J. Gough. Materials of the Wright engine and airplane, typical material features of representative British 1938 aircraft and engines (De Havilland Albatross, Short Empire flying boat, Fairey Battle, and the Bristol Hercules, Merlin II and Napier-Halford Dagger III engines), and sequence of changes in materials for important engine components in the past 30 years are reviewed. The technical survey covers: steels; aluminum alloys; modern magnesium alloys; special alloys; wood; rubber; synthetic rubbers and plastics; and methods of surface protection.

Aspects of engine, airplane, propeller and alighting gear are each dealt with separately in relation to materials employed, imposed operating conditions, and directions in which research attention can be usefully directed. Characteristics of metals are discussed, including fatigue, investigation of size effect, further studies of stress concentration effects, methods of application to design, combined fatigue stresses, fretting corrosion, abrasion and wear, and damping capacity. Royal Aeronautical Soc. Preprint for Meeting, May 26, 1938, 114 pages, 37 illus., 11 tables.

Fuels and Lubricants

Aircraft Engine Lubrication. E. L. Bass and C. H. Barton. Test results discussed include: influence of mixture strength on ring gumming in aircraft engines; effect of mechanical conditions such as piston-ring side clearance; bearing corrosion; effect of fuel on carbon formation, proportion of oil burnt to carbon, and other factors affecting carbon formation; and controlling factors in sludge formation.

Data obtained in oil tests in J.A.P. engines, in the 490-c.c. Norton and the Bristol aircooled single-cylinder engines, and in full-scale engine bench tests are given and test engines and operating conditions are described in detail. Layout of the Webber "D" bearing-corrosion test engine is shown. Authors are with the Asiatic Petroleum Company. S.A.E. Preprint for Meeting June 12–17, 1938, page 18, 4 illus., 3 tables.

How 100-Octane Fuel is Produced. Process developed by the Shell companies converts octenes to octanes by hydrogenation. Description of process. American Petroleum Institute paper entitled "The Catalytic Hydrogenation of Octenes to Octanes." Automotive Industries, June 11, 1938, pages 794, 796, 1 table.

Importance of Distillation Tests in Classifying Oils. W. L. Nelson. Importance of the A.S.T.M. distillation curve in the case of gasolines because it has been correlated to road test; A.S.T.M. distillation ranges of motor fuels; A.S.T.M. and true-boiling-point distillation curves of a third-grade motor fuel; and correlation of A.S.T.M. and true-boiling distillations. Oil & Gas Jour., June 16, 1938, pages 62, 65, 3 illus.

Remarks on Test Requirements for Aircraft-Engine Fuels Used in Spark-Ignition Engine. K. Mayer-Bugstroem and E. A. Reussner. Principles which were used as a basis in the development and setting up of these specifications, some points of view on the specifications, and possibilities for specification development are given. Luftwissen, May, 1938, pages 172–174, 1 table.

New Laboratories of the Bureau of Mines Petroleum Experiment Station. H. M. Smith. Outline of activities taking place and description of the station and its equipment. Industrial & Engg. Chemistry, Anal. Ed., May 15, 1938, pages 287–292, 12 illus.

The Study of Extreme Pressures and Their Importance in the Investigation of Engineering Problems. T. C. Poulter. Some experiments carried out in the high-pressure laboratory of the Research Foundation of Armour Institute of Technology, effect of pressure upon properties of matter, and bearing failures where an extreme-pressure lubricant is required. The author believes that before long specifications of a lubricant will be largely based upon the pressure hardness curves for not only the mixture as a whole but upon the individual constituents. Jour. Applied Physics, May, 1938, pages 307–311, 3 illus.

Metals

The Possibilities of High Pressures in Powder Metallurgy. W. D. Jones. Apparatus developed by Bridgeman in which hydrostatic pressures of the order of 700,000 lb./sq. in. were used, and its practical aspects. Metals & Alloys, May, 1938, pages 125–126, 1 illus.

Explosive Rivets. Heinkel explosive rivets used in aircraft construction. Design of rivets and the riveting operation. Drawing shows design before and after riveting. Aeroplane, February 23, 1938, 1 illus. Am. Society of Naval Engrs., Jour., May, 1938, pages 297–298, 1 illus.

The Adhesion of Bearing Alloys—Bonding of Tin-Base Alloys to Steel. E. Wood. Adhesion of the white metal used in big-end bearings for high-duty aircraft engines. Discussion covers: an original experimental procedure including grading by chisel test and X-ray and micro examination; effect of surface of liner on its adhesion; casting conditions; strength of actual bond; variation from standard technique; and problem of cooling rate. Disposition of bars of ϵ copper-tin compound in the white-metal layer immediately adjacent to the steel is more important than tin-iron compound and tinning time. Distribution, arrangement and size of bars of ϵ are governed by rate of cooling. Contents of a low carbon and manganese steel are given. Metal Industry, June 3, 1938, pages 569–573, 8 illus., 1 table.

Defects in Steel. J. A. Duma. Methods employed by investigators for obtaining data for mapping out zones of brittleness; quenching cracks; and tempering. To be continued. Heat Treating and Forging, May, 1938, pages 231–236.

Recent Research on Bearing Metals. Systematic investigation of tin-base alloys, fatigue properties, stresses due to differential contraction, adhesion of bearing metals, tests on bearings, and constitution. Metal Industry, May 20, 1938, pages 523–524.

Effect of Copper on Some Alloy Steels. R. Harrison. Properties of some nickel, chromium and nickel-chromium steels containing 1 to 5 per cent copper with special reference to susceptibility to temper hardening. Maximum increase in hardness on tempering was usually obtained by reheating at temperatures between 450° and 550° C. after air cooling from 800° C. Time necessary to reach maximum hardness was longer, the lower the temperature. Communication from Research Department, Woolwich, presented before the British Iron and Steel Institute. Engineering, June 17, 1938, pages 692–694, 3 illus., 5 tables.

Steel Castings Used in Aircraft Construction. H. v. Eckartsberg, H. Juretzek and W. Mantel. Properties of steel castings based on test results as well as numerous special investigations, covering: chemical composition, metallurgical properties and structural condition; static strength properties; impact values; dynamic strength properties; and other general properties based on acceptance tests. Report of Research Laboratory, Ruhrstahl A.-G. Luftwissen, May, 1938, pages 167–171, 6 illus., 3 tables.

Plastics

Tests on Synthetic Materials for Aircraft Structures. K. Riechers. Composition of synthetic materials, strength properties of conventional compressed materials and possibilities for their improvement, compressed materials at continuous load, DVL tests on aircraft structural parts of compressed materials, and practical applications of these materials in aircraft structures.

Data include: strength of glued joints of synthetic-resin compressed materials; nonlaminated and laminated synthetic-resin compressed materials; reinforced synthetic resin at various high pressures; and synthetic-resin compressed materials with various synthetic-resin insertions. Curves illustrate: compressive strength and specific weight of powdered-wood compressed materials for various powdered wood content; strength of reinforced synthetic resin at various high pressures; resonance of steel and reinforced synthetic resin (absorption of latter is 140 times larger than for steel); rigidity of reinforced synthetic resin and pine wood in percentage of tensile strength for short-period loads; rotary bending tests with compressed materials; and determination of fatigue bending strength on synthetic-resin compressed materials from modulus of elasticity measurements. V.D.I., May 28, 1938, pages 665–671, 7 illus., 4 tables.

Meteorology

The Formation and Dissipation of Stratus Clouds Beneath Turbulence Inversions. Lt. F. B. Wood. Investigation into formation of turbulence inversions, and analysis of physical processes connected with formation and dissipation of stratus-type clouds frequently found just beneath the bases of such inversions. Immediate cause of the formation of these stratus clouds is adiabatic cooling through convection, and clouds so formed tend to intensify inversion through radiation. Abstract M.I.T. Prof. Notes No. 10. Am. Meteorological Soc., Bul., March, 1938, pages 97–103, 6 illus.

Influence of the Speeds of Winds on the Future Services over the North Atlantic. Statistics regarding the conditions of winds at high altitudes over the Atlantic Coast of the United States are quoted from the Monthly Weather Review, No. 36 and are discussed. Variation of the wind conditions at altitude, and seasonal and altitude variations for the zone between the 30° and 45° parallels are considered. L'Aéronautique, March, 1938, pages 49–50, 2 tables.

Maps of the Pressure Distribution in the Middle Troposphere, Applied to Polar Anticyclones. B. Haurwitz and J. R. H. Noble. Methods used in drawing isobars for the upper air charts; preparing maps at the desired upper levels; plotting pressure distribution at a given height; plotting topography of a standard isobaric surface; and discussion of results. Royal Society of Canada paper. Am. Meteorological Soc., Bul., March, 1938, pages 107–111, 6 illus.

Studies of Synoptic Free-Air Conditions for Icing of Aircraft. E. J. Minser. Regions of most severe icing are associated with frontal surfaces. Vertical convection sustains large water droplets and thereby induces severe icing in temperatures below freezing. Cloudiness associated with strong convection should be avoided. Temperature inversions to above freezing do not always exist above ice-forming regions, even when freezing rain occurs, and escape from ice by climbing should not be attempted unless existence of above freezing temperatures at higher levels is definitely known.

Ice evaporates very slowly in clear cold air and an accumulation of ice induces rapid collection of more ice if descent is made through a cloud deck in which liquid droplets predominate and temperature is 32° F. or lower. Thorough study of latest synoptic chart to determine position, slope and tendency of fronts before flight is attempted is only means by which ice forming regions may be located and probable intensity of ice determined. Short note by C. F. Brooks describes an unusual case of icing. Institute of the Aeronautical Sciences paper. Am. Meteorological Soc., Bul., March, 1938, pages 111–122, 9 illus.

Dispersion of Fog over Airports. J. Thoret. Previously reported research of the British Aeronautical Research Committee on the dispersion of fog by means of chloride of calcium or of heat is discussed. The author suggests that descending winds for dissipating the fog could be created by propellers located around the airports and the simultaneous use of heaters. L'Aéronautique, April, 1938, page 78, 2 illus.

Geography and Rainfall of the Nebraska Sandhills. B. E. Hall. Discussion of precipitation in the sandhills area and climatological data from the U.S. Weather Bureau. Monthly Weather Rev., February, 1938, pages 36–38, 5 tables.

The Normal Temperature Distribution of the Surface Water of the Western North Atlantic Ocean. G. Slocum. Charts for the twenty-year period, 1912–1931 prepared from data on water-surface temperatures measured by observers aboard ships cooperating with the Marine Division. Two methods of taking the temperature and results of measurement are discussed. Monthly Weather Rev., February, 1938, pages 39–43, 17 charts.

Radio Soundings Taken on Board the "Carimaré." R. Bureau and A. Perlat. Radio soundings taken in the air over the ocean by the Carimaré, French stationary meteorological ship in the North Atlantic. Characteristics of the radio-operated balloons used; French system for transmitting the measurements taken by the balloons, and definition of the angle by a number of impulses; some indications relative to the sounding balloons; receiver and recording; calibration of the balloons; and installations and arrangement on board ship. L'Aéronautique, April, 1938, pages 71–78, 13 illus.

Engine Design and Research

Air Diesels. British research on the heavy-oil compression-ignition engine is continuing and progress has been encouraging. So far results still show a vast disparity in performance compared with gasoline engines. No compression-ignition engines are in use in Service aircraft but flight development trials of one are taking place. Brief reference to statement of Secretary of State for Air. Aeroplane, May 25, 1938, page 627.

Critical Observations on the Evaluation of Resonance Vibration Dampers. O. Foeppl. Evaluation of the most favorable damper friction, excluding the main vibration arrangement; various dampers of different dimensions at similar r.p.m.; examination of the general arrangement of damping vibration systems with dampers; and influence of the position of the vibration nodes on the rocking of the vibration. A.T.Z., May 25, 1938, pages 265–267, 2 illus.

Cylinder Cooling, and Drag of Radial Engine Installations. K. Campbell. If submerged or full-streamlined installations in high-speed airplanes come into consideration, fan cooling may become a very satisfactory type of automatic controlled cooling. Full-scale laboratory tests with a fan attached to the propeller of a 16 : 11 gear-ratio Cyclone demonstrated that at least 3 in. of water boost was available at take-off r.p.m., the blades being designed to float or produce no boost at the higher flows resulting naturally from high-speed cruising flight.

Discussion covers: fin design; laboratory and flight tests on three widely differing types of baffles at Wright Aeronautical Corporation; effect of turbulence on cooling; design of cowl exit slots; results with the "reverse flow" or forward-exit type of slot cowl; promising outlook with the one-way flow type wherein air enters from the rear and passes forward through all baffle passages in parallel and out through a forward slot, conventional or otherwise; and conversion to pressure of the velocity energy of air displaced in a tangential direction by propeller shanks and application to a Cyclone engine on the WAC General airplane. S.A.E. Preprint for Meeting, June 12–17, 1938, 30 pages, 18 illus.

Cylinder Wear. G. I. French. Suitably oxidized magnesium-aluminum alloy surface covered with a mixture of aluminum and magnesium oxides on polishing interacts to form spinel with a permanently amorphous and smooth Beilby layer. Laboratory experiments have shown reduction in wear with such spinelized surfaces as compared with anodized aluminum. Theories on the structure of worked and polished surfaces are outlined, and the reasons why the Beilby layer should be formed on bearing surfaces are given. Automobile Engineer, May, 1938, page 166.

Damping of Torsional Vibrations by Means of Hydraulic Couplings. F. Soechting. Influence of hydraulic couplings frequently used in geared drives and between internal-combustion engines and heavy machines. Vibration deflection is calculated and it is shown that the vibration-absorption effect of the hydraulic coupling is present at each position of the node as well as at each r.p.m. V.D.I., June 4, 1938, pages 701–703, 2 illus., 11 equations.

Diesel vs. Spark-Ignition Engines in Aviation. F. Ricard, Chief Engineer of the French Air Service. Mounting of both gasoline and Diesel engines in the same multi-engined airplane is suggested, take-off being effected with all engines running and cruising on the Diesels with reduced output of the gasoline engines. Development of an engine having the good features of both types and a compression ratio of 10 is possible. For take-off it could be operated as a carburetor engine by a supply of high-octane fuel, and for cruising operated by injection of gas oil.

Superiority of the Diesel for cruising and its inferiority for take-off and climb at maximum speed is discussed in detail with weights and fuel consumptions of both types of engines. From La Technique Moderne, June 1. Automotive Industries, June 25, 1938, pages 833, 837, 2 tables.

Injection of Diesel Fuel into Flame Cuts Ignition Lag Only Moderately. P. H. Schweitzer. In an investigation with an engine having two completely independent injection pumps and nozzles, zero ignition lag was never observed. Not only first fuel droplets but also all subsequent droplets are delayed by an ignition lag. This lag while injecting into flame is almost entirely of chemical nature and the presence of flame does not accelerate chemical reactions in the adjacent mixture about to ignite. Description of test. Automotive Industries, June 25, 1938, pages 848, 854, 3 illus.

A Precombustion Ignition Coal Oil Engine. J. R. Kingston and W. R. Powell. Early work with a separate combustion chamber, and later experiments with a continuous combustion engine and with one fitted with auxiliary injectors on the power cylinders to spray oil fuel into the excess air contained in the combustion products.

Continuous combustion engine could be easily arranged to work on the Carnot cycle if, in addition to the fuel pump for the combustion chamber, an ordinary oil-engine pump and injector were added to each cylinder to maintain isothermal expansion. Difficulties are pointed out. Engineer, June 10, 1938, pages 641–643, 6 illus., 7 equations.

The Single Sleeve as a Valve Mechanism for the Aircraft Engine. A. H. R. Fedden. Short historical outline of sleeve-valve development; research work at the Bristol company carried out by the author to date; main engine developments; and most important advantages inherent to the single-sleeve-valve aircraft engine. Various Perseus models, the Aquila and the Hercules engines are referred to. The author asks why "direct fuel injection has not made greater strides in America, in view of the considerable start given to this project by the Army some years ago." S.A.E. Preprint for Meeting, June 12–17, 1938, 22 pages, 13 illus.

Sparking Plugs in Aero Engines. F. R. F. Ramsay. Much larger capacity connected in parallel with the points through use of screened cable or screening harness, and higher speeds and temperatures are causes of increase in point erosion. Nature of the spark and effect of the screening are analyzed. Research carried on in the laboratories of D. Napier and Son, Ltd., in collaboration with K.L.G. Sparking Plugs, Ltd., is described and drawing is given of the K.L.G. BR90 elbow with a high-tension contact assembly with 1000-ohm resistor. Flight, June 2, 1938, pages 557–558, 2 illus.

Spray Penetration. P. H. Schweitzer. Spray penetration formulas given in "Recent Developments in High-Speed Oil Engines," by S. J. Davies, previously published, are criticized on the ground that they are based on an incomplete theory assuming that spray disintegration is caused solely by a disturbance within the nozzle, and air friction has no effect on it. Data on spray penetration measured at Pennsylvania State College, and their correct calculation, as well as other data, fail to support Mehlig's formula give by Davies. Letter to the editor. Engineering, June 17, 1938, page 688, 2 illus., 5 equations.

Supercharger Installation Problems. A. L. Berger and O. Chenoweth. Possibility of obtaining take-off power by use of an exhaust-driven supercharger applied to an aircraft engine having a low blower gear ratio is indicated in the dynamometer data given. Importance of the airplane installation on general efficiency and performance of the supercharger is stressed. Relative influence of supercharger inlet temperature, supercharger inlet-duct

pressure drop, and intercooler pressure drop are evaluated. Amount of power required to drive superchargers of large engines is discussed and installation efficiency is established as a measure of how well the supercharger installation has been accomplished. S.A.E. Preprint for Meeting, June 12–17, 1938, 36 pages, 23 illus.

Point of Ignition in Air-Chamber Diesels. A. Loschge and F. Kneule. Investigation to determine whether in a Diesel engine of the air chamber type, combustion is initiated in the air chamber or main chamber. Air chamber of the test engine communicated with the main chamber through a series of perforations in a plate or insert on which the fuel spray impinges from the main chamber side. Moments at which combustion began on opposite sides of the plate were determined by the ionized gap method. Ignition always took place close to the hot burner plate and on either side with the usual degree of injection advance. Abstract from ATZ, April 25. Automotive Industries, May 28, 1938, page 715.

Engine Testing

Determining Bearing-Film Temperature. C. G. Williams and J. Spiers. Engine and test bed apparatus; bearing temperature measuring apparatus; and the effects of oil-inlet temperature, rate of oil circulation, engine speed, oil viscosity, and load. Report of Research and Standardization Committee of the Institution of Automobile Engineers. Automotive Industries, May 28, 1938, pages 724–728, 18 illus.

FKTS Whirling Air Brakes. Whirling air brake with which the setting of the propeller can be altered during engine operation. Brake was specially developed by the Automobile Research Institute of the Stuttgart Technischen Hochschule for tests on aircooled aircraft engines up to 100 hp. In contrast to the air brakes with fixed blade setting, a change of brake moment and also a measurement of engine power at various r.p.ms. at fixed throttle are obtained. A.T.Z., May 10, 1938, pages 251–252, 4 illus.

Measuring Apparatus for a Simple Determination of Mechanical Vibration. F. Allendorff. Apparatus developed in the research laboratories of Robert Bosch, G.m.b.H., by means of which mechanical vibration, rectilinear and torsional vibration, may be measured and quickly evaluated. Apparatus consists of a light recorder, switch apparatus with time recording and the various contacts, which receive the mechanical vibrations and pass them on to the light recorder through control of electrical circuits. Various measuring sizes and various composite vibration processes can be recorded simultaneously. From the records the magnitude of the vibrations and with it the dynamic stresses can be determined and strength ratio easily evaluated. Applications to the determination of vibrations existing in an internal combustion engine and in its auxiliaries are described. V.D.I., May 14, 1938, pages 569–574, 25 illus.

University of Michigan Automotive Laboratories. J. Geschelin. Equipment for research and tests for the aircraft and automobile industries. Automotive Industries, May 19, 1938, pages 720–722, 736, 5 illus.

Engine Fuel and Lubricant Testing

1937 Road Knock Tests. T. A. Boyd. S.A.E. Jour. (Trans.), June, 1938, pages 244–252, 4 illus., 13 tables.

Knock Testing in Laboratory and in Service. G. Edgar. Service knock tests on aviation fuels carried out on aircraft engines attached to a dynamometer under both rich-mixture take-off and lean-mixture cruising conditions are described in the airplane section. Different laboratory test methods for different octane-number ranges may need to be developed, chemical tests may be necessary to eliminate certain types of fuel, and it may prove desirable to develop two tests at varying "severity levels" to evaluate properly fuels of high sensitivity to conditions of tests. Knock testing cars on the road, laboratory knock testing, and correlation of the two also discussed. S.A.E. Preprint for Meeting, June 12–17, 1938, 19 pages.

Rating Aviation Fuels—in Full-Scale Aircraft Engines. H. K. Cummings. Canadian tests show satisfactory agreement with results of the first report. Wright Aeronautical Corporation supplementary tests of olefinic fuels show the A.S.T.M. method satisfactorily predicts full-scale value of very highly unsaturated fuels of both leaded and unleaded type. Tests of commercial 87 A.S.T.M. octane number and 100 Army octane number fuels (made by Wright Aeronautical Corporation and Pratt-Whitney) indicate that the A.S.T.M. method underrates 87-octane leaded fuels by 6 to 8 octane numbers and 100-octane leaded fuels by 2 to 4 octane numbers. Test engines, fuels used and test results described, present status discussed, and future work outlined. Completion of first program and progress on the second program —Report of the Cooperative Fuel Research Committee. S.A.E. Preprint for Meeting, June 12 to 17, 1938, 23 pages, 8 illus., 3 tables.

Engines

Alfa Romeo Brings Forth a Two-Stroke Diesel. Automotive-type vee two-stroke Diesel engines have been built in six- and twelve-cylinder sizes, a single cylinder size being used for both (bore 3.74 in., stroke 5.12 in.). Combustion chamber is located in the crown of the composite piston. As there is very strong air turbulence in the combustion chamber, single-jet injection can be used. Six-cylinder engine is rated at 110/115-hp. Scavenging air is provided by a Roots blower. Long description and drawing of the special type of governing system. Automotive Industries, June 11,1938, pages 784–786, 5 illus.

G-100 Series Wright Cyclone Engines. Modifications included in the two advanced versions of the Cyclone G 9-cylinder radial aircooled engines, which are designed to increase power and performance and lower fuel consumption. The GR-1820-G 102 is rated at 1100 hp. for take-off and provides 900 hp. at 2300 r.p.m. from sea level to 6500 ft. The GR-1820-G 103 is rated at 1000 hp. for take-off and gives 860 hp. at 2300 r.p.m. up to 10,500 ft. Both engines have 16:11 propeller speed reduction gear and differ only in their supercharger drive gear ratios. Long description. Aero Digest, June, 1938, pages 67–68, 7 illus. Aviation, June, 1938, pages 34–35, 65, 4 illus.

German Aircraft Engines. P. H. Wilkinson. For high-speed lightweight type of Diesel for airplanes, the two-cycle design with its high efficiency and low fuel consumption has been found most suitable, while for airships, the slower four-cycle Diesel is preferred.

Junkers Jumo 207 for military airplanes is rated at 750 hp. at 20,000 ft. It has an exhaust-driven two-speed supercharger, the centrifugal supercharger being driven through gearing for ground boost and at low altitudes, and the exhaust-gas driven turbine being cut in at high altitudes. Mercedes-Benz DB602 Diesel for airships is not supercharged but has a displacement of 5401 cu. in. and maintains an output of 1200 hp. at 1600 r.p.m. at sea level. Few details of these engines as well as of the Junkers Juno 205, 205C, 205D, and 205E engines. Concluded. Aviation, June, 1938, page 38, 2 illus.

Unitwin Power. Sketch showing the possibility of connecting two engines to one propeller, and a reference to the power plant being developed by the Menasco and Lockheed companies in which two 250-hp. Menascos are connected to one propeller. Scientific Am., June, 1938, page 352, 1 illus.

An Altitude Performance of the Clerget Heavy-Oil Engine. R.-J. de Marolles. Altitude record made last December by the Potez 25 fitted with a Clerget 14 F-01 500-hp. engine. Altitude of 7655 meters was attained in about 37 minutes. Description of flight, engine, and other equipment used. A small number of Clerget 14 F-01 engines have been built to equip different types of single and multi-engined airplanes. The 14 F-01 has 14 cylinders in double-row radial arrangement of 140 mm. × 160 mm. Barogram of the flight shown. L'Aéronautique, April, 1938, pages 79–82, 2 illus.

Can Aviation Utilize Heavy Fuels. Stewit. Stewit injection pump uses fuels without viscosity such as gasoline. In the Stewit engine, combustion chamber is designed so that air is divided into vortices of different speeds and so that the centrifugal force promotes the formation of several centers for the different phases of combustion. At the beginning of combustion mixture is very rich, then when oxidation is produced, it is less, and then at the end of combustion the fresh air arrives in abundance.

In research undertaken to produce, in a combustion chamber of large capacity, pressures not exceeding those existing in the spark ignition engine, injection in two stages was studied. The first was very short with electric ignition and the combustion warmed the mixture to 400°, or the air is compressed very rapidly to 34 kg. Gas oil was atomized in a special manner to acquire certain unusual qualities. The atomizer throws out a sort of foam possessing certain electrostatic charges. For a four-cycle engine without valves the spherical distributor was developed and used with a pressure stabilizer. Development of these Stewit engine parts and results obtained in tests with them. Swiss research. L'Aérophile, May, 1938, pages 109–111, 5 illus.

A Civil Perseus Type Tested. Bristol Perseus X engine developed in particular for high-altitude high-speed fighting aircraft has recently passed its type test and is rated at 880-hp. at 15,500 ft. Overall diameter is 52 in. Although fully supercharged with 3-lb. boost at 2650 r.p.m., take-off output is 750 hp. International rating is 700/730 hp. at 14,500 ft.

A specially developed Perseus XII-C of 24.9-liter capacity will be the first commercial sleeve-valve aero engine in the world to be put into series production. Maximum rating (5 min.) 815 hp. at 2600 r.p.m. at 6000 ft. Maximum take-off 900 hp. at 2700 r.p.m. Imperial Airways has flown the engine nearly 2000 hours. Short note. Flight, June 2, 1938, page 547.

Brief note. Aeroplane, June 8, 1938, page 731.

Description of Perseus XII-C and X. Table of characteristics and performance includes also the Perseus XI and XII medium supercharged engines. Aeroplane, June 15, 1938, pages 751–752, 3 illus., 1 table.

Development of a Series of Engine Mounts. R. Vogt. Cast steel mount for the Jumo 210 engine; riveted box-girder engine mounts used on the Ha137 and Ha139 aircraft; riveted box-girder mount for the Jumo 210 engine; and the formed tubular support for the Jumo 205 engine. These mounts and their advantages are discussed. Luftwissen, May, 1938, pages 164–166, 7 illus.

Horus 30–35 Hp. Engine. French Horus 4-cylinder flat-twin engine having a cylinder capacity of 1.5 liters. Long description. L'Aérophile, May, 1938, pages 113–114, 1 illus.

The Standard Shadow Factory. Specialized production methods used for Bristol Mercury cylinder units. Checking the fins and operations on the cylinder barrel and head are described. Concluded. Editorial criticizes the waste of effort due to the fact that the engine was not designed for mass production methods now necessary. Automobile Engineer, May, 1938, pages 154–156, 5 illus.

Some Fiat Impressions. Fiat aircraft engines and bombers and fighters in production. Although liquid-cooled engines are still going through the works, (chiefly for Fiat C.R.32 fighters) an aircooled policy has been adopted and has seen fruition in two types of two-row radial, the A.80 18-cylinder and A.74 fourteen. To tide them over the development period, a number of Pratt-Whitney Hornets have been built. A.80 R.C.41 in large-scale production gives 1000 hp. at 13,000 ft. for weight of 1600 lb. The A.74 R.C.38 powering the Fiat G.50 fighter delivers 840 hp. at 12,500 ft. Flight, June 9, 1938, pages 565–566, 5 illus.

Technical Notes. In the new U-shaped Diesel engine designed by M. Botali, a volumetric scavenging pump is furnished for each engine element. Piston in front of the U draws back the crankpin on the rear piston which uncovers the air inlet ports connected to the compressor. Combustion chamber is composed of a charging channel between the two cylinders. In order to obtain the compression ratio desired and to have a suitable form of combustion chamber, the two pistons carry covered deflectors, each of a cap of steel of high thermal resistance, which offer protection against the flame. Drawing given. Les Ailes, May 26, 1938, page 7, 1 illus.

Technical Notes. Humbold-Deutz two-cycle radial heavy-oil engine. Crankcase has a double wall and forms the air inlet receiver. Two Roots volumetric superchargers mounted on the rear surface of the engine furnish the scavenging air. Drive is by a unique gear keyed to the end of the crankshaft. Drawing and the above details only. Les Ailes, June 2, 1938, page 7, 1 illus.

Technical Notes. In the two-cycle engine developed by M. Kipfer distribution is by a sleeve operating in direct connection with an exhaust-gas turbo-blower. Each cylinder carries inlet and exhaust ports above, and below are two superposed rows of exhaust ports. Ports above are uncovered to transmit the "puffs" of exhaust. Lower ports are opened in their turn and the rest of the exhaust is conducted to a collector so that exhaust gas at low kinetic energy does not pass into the turbine blades. Principle is similar to that of the Rateau-Potez having a double distribution for utilizing only the puffs in the turbine. Drawing and short description. Les Ailes, May 26, 1938, page 7, 3 illus.

Parts and Accessories

A New System for Cooling Radial Engines. P. E. Mercier. Cooling air is admitted at the back of the propeller by an adjustable annular section directed towards the engine axis by a fairing following the propeller spinner. Inlet channel has a section progressively increasing and reducing speed of the air before it reaches the cylinder fins. Speed at inlet is 75 per cent of airplane speed.

Patented deflectors assures deflection of air around the cylinder barrels in four layers giving maximum cooling where the piston bears on the cylinder. Air cooling the cylinder barrels is heated only to 10° and then is directed on the head. Air is evacuated through an adjustable annular slot like a converging nozzle.

Description of research at the SNCA du S-E, operation of the Mercier cowling and exhaust gas system, results of tests, and comparison with NACA cowling. Gnôme Rhône has developed a fairing for propeller blade roots to improve propeller efficiency and suppress the turbulent zone in the center of the cowling. Cowling has been tested on Gnôme-Rhône engines in a LeO-46 two-engined prototype float seaplane. Les Ailes, June 2, 1938, page 8, 4 illus.

Aircraft Radio

Instrument Landing—Today and Tomorrow. H. W. Roberts. Use of Air Track, Bendix, and I. T. & T.'s Lorenz systems of instrument landing in the United States; Sperry indicator using the cathode-ray principle and giving simultaneous and automatic indication of six individual readings on a single dial; opinions of W. E. Jackson, Bureau of Air Commerce Radio Development Chief; Metcalf-MIT system based on three transmitters located on the field, received directionally on board the aircraft and indicated, both in zenith and azimuth, on a cathode-ray indicator; and a reference to the use of infra-red radiations instead of radio-frequency radiations for landing. Identical instrument-landing system for both commercial and military aircraft is recommended although the Army-Hegenberger system has been turned down by the commercial airlines and the commercial systems by the Army. Aero Digest, June, 1938, pages 79–80, 98, 2 illus.

Reduction of Night Error by the Adcock Receiving Antenna. H. Busignies. Installations at Bordeaux and Norrkoeping are described, including an antenna of the Bordeaux-Mérignac RC6-A radio goniometer in a steel tube, and the group of five antennas of the Swedish Norrkoeping radio goniometer, consisting of prisms supported by wooden posts. Adcock RC6.B semifixed radio goniometer carried on a truck, in which the French Air Ministry is interested, is described in detail. Concluded. L'Onde L'Electrique, April, 1938, pages 195–210, 11 illus.

Radio Design and Research

Characteristics of the Ionosphere at Washington, D. C., March, 1938. T. R. Gilliland, S. S. Kirby and N. Smith. Data on critical frequencies and virtual heights of the ionosphere layers, and maximum frequencies which could be used for radio communication in latitudes approximately that of Washington. Night critical frequencies and maximum usable frequencies for March were considerably greater than those for February. Inst. Radio Engrs., Proc., May, 1938, pages 640–643, 2 illus., 3 tables.

Aeronautical Industry and Production

April Aircraft Exports Eclipse 1937 Dollar Value for Same Month by 168 Per Cent. Statistics for export of aircraft and automotive parts. Short article. Automotive Industries, June 4, 1938, page 738.

Company Activities. Activities at the Bell, Bendix, Boeing, Consolidated, Curtiss-Wright, Douglas, Hamilton Standard, Herberts, Lockheed, North American, Pacific Airmotive, Piper, Poyer, Ryan, and Taylorcraft companies, with brief references to some Army Air Corps orders. Brief notes. Aero Digest, June, 1938, pages 11–12, 1 illus.

Consolidated Celebrates Its Fifteenth Anniversary. Development of Consolidated Aircraft Corporation to its present position is traced with details of some of the military and commercial aircraft produced. Long article. Aero Digest, June, 1938, pages 34–39, 29 illus.

Curtiss-Wright Expands Engineering and Production Facilities. G. W. Vaughan. Expansion program fulfilled at the Wright Aeronautical Corporation plant, new plants completed in Buffalo for the production of aircraft and propellers, and changes made in the St. Louis Airplane Division plant. Aero Digest, June, 1938, pages 40–42, 83, 11 illus.

Factory Resources in Canada. Even with large orders on hand for the Defence Department, none of the Canadian aircraft factories are working to full capacity and additional orders can therefore be accepted without enlargement of plants. All manufacturers willingly offered their entire facilities to Canada and the United Kingdom. Short note on meeting of twelve Canadian aircraft manufacturers and the Canadian Deputy Minister of National Defence. Aeroplane, May 18, 1938, page 595.

Sales up 48 Per Cent. Units and values for production and deliveries of airplanes and engines for the first quarter of 1938 compared to the same period in 1937. Deliveries total $31,923,443 and military airplanes lead. Short note. Western Flying, June, 1938, page 28, 1 table.

War Aircraft Plant Planned for Canada. Miller-Bellanca Aircraft Corporation plans to establish a Canadian plant later in 1938 for production of military airplanes whose design has already been submitted to the British and French governments. One airplane to be produced will be a twin-bodied transport or bomber powered with two 1000-hp. engines in tandem and having a speed of 300 m.p.h. Brief reference. Iron Age, June 2, 1938, page 98.

Still More Factories. Rolls-Royce, Ltd. will erect a 50-acre aero-engine factory at Crewe to employ over 4000 men. Brief reference to this report and to negotiations for Lord Nuffield's aero-engine factory near Birmingham. Flight, June 9, 1938, page 580.

Lord Nuffield. It is said that Lord Nuffield has consented to set up a mass-production aircraft factory in or near Birmingham to turn out 5000 aircraft a year. Brief reference. Aeroplane, June 1, 1938, page 656.

Pilots

48 Hours in a Low-Pressure Chamber. Effect on pilots of remaining at an altitude of 7000 meters for a number of hours has been studied at the medical center at Bourget. Dr. Richou and M. Artola entered a low-pressure chamber in which the pressure was decreased to that corresponding to 7000 meters altitude and remained there 48 hours. The two operators were supplied with oxygen by breathing masks which were raised in order to eat or to swallow. They passed their time in making observations on themselves as well as on birds and gold fish. Brief note. Les Ailes, May 26, 1938, page 4.

Physiological Demands of the Human Organism in Stratosphere Flights. Suitable Means to Increase the Adaptability and Resistance of the Man in Flights in Relation to Altitude and Duration. M. Marinucci and S. Gaulco. New medical problems connected with the human resistance and adaptability to acceleration and pressure changes due to high altitudes. Recent studies indicate that lack of oxygen is but one aspect of flying at altitudes above 15,000 ft. Existence of reduced pressure affects not only respiratory organs but also blood circulation, gland secretion, functioning of the nervous system, and the five senses of perception.

Men of robust physique and good health under normal conditions may show less adaptability to variation in conditions and effects of lower pressure. Requirements to be possessed by an individual to make him an efficient high-altitude pilot are pointed out. Use of atropin and belladonna are suggested as possible means of preparing the organism for high-altitude flying. Abstract from Rivista Aeronautica, March. Aero Digest, June, 1938, page 95.

Air Forces

The Royal Navy (Air Branch). Strength of the Fleet Air Arm is 214 airplanes, ten airplanes more than last year. No material increase can be made until new aircraft carriers and other warships are completed. Strength of the U.S. Naval Air Service is 705 airplanes which includes 198 flying boats attached to the Fleet. Japanese naval air strength is 271 airplanes and German 16 airplanes, these figures not including land-based airplanes. Brief reference. Aeroplane, May 25, 1938, page 631.

American Aircraft for Great Britain

A National Disgrace. "To order American aeroplanes of any sort is an imbecility." Severe criticism of the British contracts with American manufacturers for 200 general reconnaissance and 200 advanced trainers and of the airplanes themselves. These are said to be the militarized version of the twin-motored Lockheed 14 and North American BT-9B two-seater trainers. Suitability of the Lockheed is questioned and the North American is more severely criticized. Orders for Phillips and Powis Kestrel trainers and for Airspeed Oxfords are also reported. Aeroplane, June 15, 1938, pages 733–734, 1 illus.

Afghanistan

Afghan Air Force. Twenty-four airplanes from Italy and 22 from Great Britain so far have been dispatched by road through Khyber Pass for Kabul. A number of Afghan youths are being trained in England, Russia and Italy. Airports have been planned at Hirat, Kandahar, Muzari Sharif and Jalalabad. Brief reference. Flight, May 19, 1938, page 490a.

Canada

Foreign News. Canada has voted $10,753,617 for the fiscal year 1938–39 to provide for 75 new airplanes, ammunition, five air bases on the Pacific coast, and an addition of 480 officers and men to the Royal Canadian Air Force. Part of a defense appropriation of more than $34,000,000, most of the air appropriations will be spent on the defense of the British Columbia coast. Airplane appropriations amount to nearly $4,000,000. Short note on defense measures. Aero Digest, June, 1938, page 29.

The Four Winds. Canadian Car and Foundry Company of Montreal is to manufacture in Mexico, for the Mexican Government, 40 Grumman aircraft and 10 Trainers during the next two years. Machinery is being removed from Montreal to Mexico. Brief reference. Flight, June 2, 1938, page 548.

France

Air Activities of the Armée de l'Air in 1937. Exercises and maneuvers are discussed and a table given showing hours of day and night flying from 1922 to 1937. Rev. de l'Armée de l'Air, April, 1938, pages 458–464, 1 illus., 1 table.

French Air Strength. Provision has been made for a first-line strength, by April, 1940, of 2600 machines, 900 being fighters. Delivery of American Curtiss P.35 fighters is to begin in November and to be completed by April, 1939. Brief reference. Flight, June 9, 1938, page 568.

Curtiss-Wright. French Air Ministry has announced that 100 Curtiss P-36 pursuit airplanes powered by 1000-hp. engines have been ordered. These will have fixed landing gear compared with the retractable landing gear on the U.S. Army's production P-36A. Brief reference. Aero Digest, June, 1938, page 11.

Defense of the National Airplane. A. Corthier. Arguments against equipping the Armée de l'Air with American or other foreign airplanes. Les Ailes, May 19, 1938, page 8.

French Air Minister's Plans. Program proposed by G. La Chambre, the new French Air Minister, to increase the supply of aircraft, and dealing with organization, plan for aircraft, budget requested, production, purchases of aircraft from other countries, prototypes, personnel, North Atlantic air transport, and private aviation. Les Ailes, May 12, 1938, pages 3–4.

Germany

Incorporation of the Austrian Air Force in the Luftwaffe. Announcement and a few details of the equipment and formations of the Austrian Air Force before it was taken over by Germany. This note is followed by a short article on the Austrian commercial airlines at the beginning of 1938. L'Aérophile, May, 1938, pages 102–103, 1 illus.

Great Britain

Balloon Barrage Progress. Three balloon barrage squadrons of the Auxiliary Air Force has commenced to form and seven other auxiliary balloon squadrons are to be formed shortly. Training and entry requirements for the squadrons are referred to. Lower age limit is 38. Brief note. Flight, May 19, 1938, pages 489, 490a, 1 illus.

Brief note on conditions of service and training. Aeroplane, May 18, 1938, page 608.

The Expanded Royal Air Force. Major F. A. de V. Robertson. Constitution and administration of the Home Command, including Bomber, Fighter, Coastal and Training Commands, the defence of London and the Armament Group. Charts show organization of Air Council as well as that of the Air Ministry's operational, technical and other departments. New barrage balloon is illustrated. Flight, May 26, 1938, pages 506–514, 9 illus., 2 tables.

Foreign News. Revised estimates of officers and other personnel needed for the R.A.F. call for 1500 more pilots, 15,000 men and 4000 apprentices during the year, but it is expected that these estimates will be exceeded by actual enlistments. Brief reference. Aero Digest, June, 1938, pages 29–30.

The Royal Air Force. Present strength of that part of the R.A.F. which most closely concerns people at home includes 25 Fighter Squadrons, 71 Regular Bomber Squadrons (including two bomber-transport squadrons) 19 Squadrons in the Auxiliary Air Force (11 Bomber Squadrons, 5 Fighter Squadrons, and 3 Army Cooperation Squadrons) and 17 General Reconnaissance Squadrons. Training of pilots is likely to be the "bottle-neck" limiting rate of expansion. Brief editorial. Flight, May 26, 1938, page 503.